HFDC01
Production report

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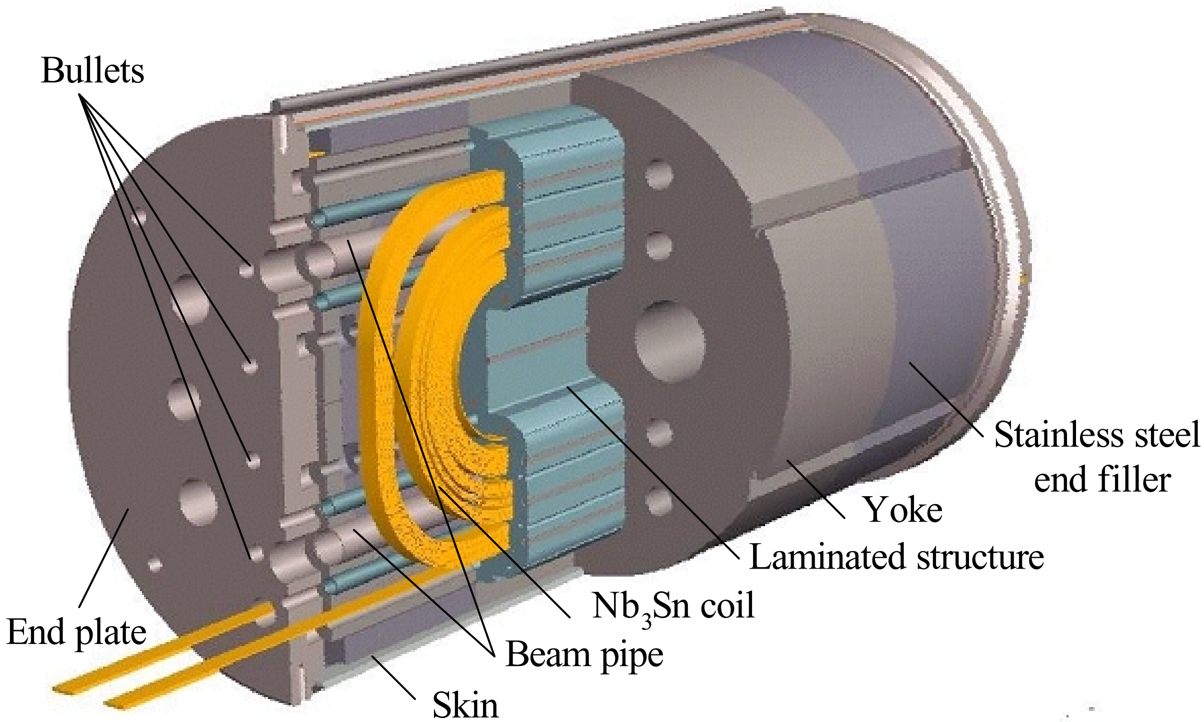


Fig. 1. Common Coil Dipole Cold Mass.

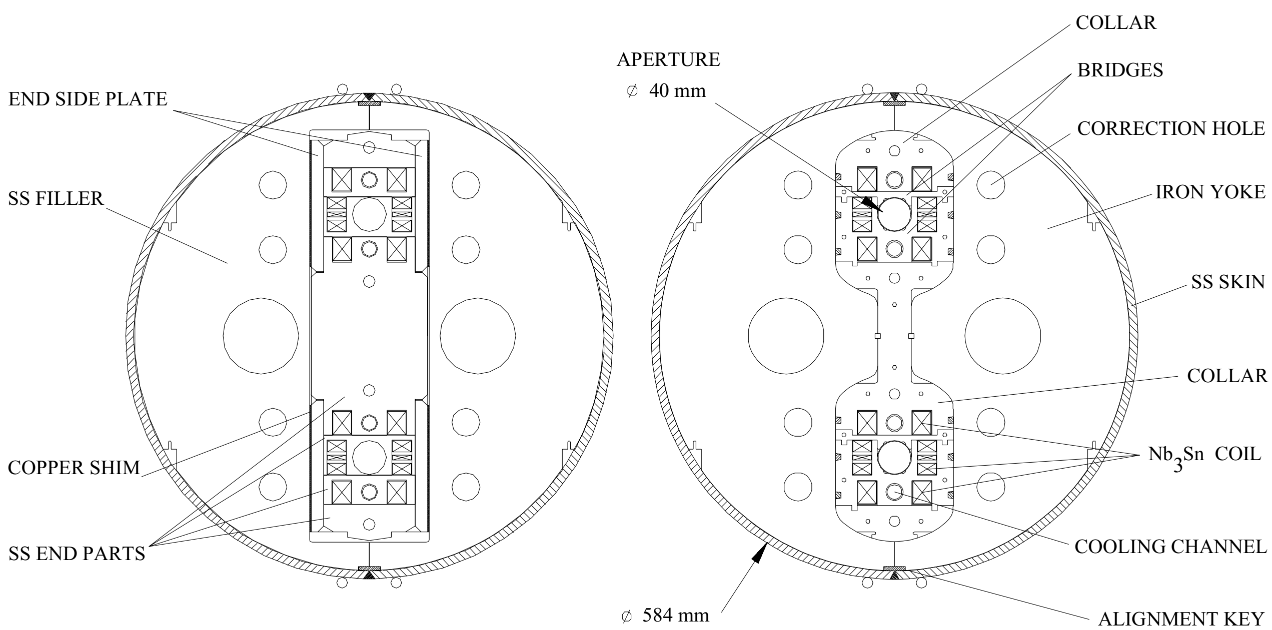


Figure 2. Two side views on magnet transition region.

A Common Coil Magnet is a short model of the main double-aperture dipole for a Very Large Hadron Collider [1]. Design parameters are listed bellow.

Magnet parameters

B_{max}, T	10.85
I_{max}, kA	25.6
Aperture, mm	40
Aperture separation, mm	290
Coil area, cm^2	2x27.7
Number of turns per coil	18+22+18
Iron yoke OD, mm	564
Stored energy @ 11 T, kJ/m	2x496
Inductance @ 11 T, mH/m	2x1.475

Table 1. Magnet parameters.

Cable characteristics

Material	Nb_3Sn
Cable type	Rutherford
Dimensions, mm^2	22.23 x 1.28
Strand diameter, mm	0.7
Number of strands	60
Strand Jc (12 T 4.2 K)	3000
Jc total degradation	20%
Cu/Non_Cu	1

Table 2. Cable parameters.

The Technological Model was build before starting of magnet production [2]. Table 3 summarized the Tech-model difficulties and recommended solutions. All these recommendations had been implemented.

Item	Problem	Reason	TM solution	Magnet solution
Cable	Damage of the cable strands after reaction Welded cable ends on the spool cause cable distortion on the last turn after reaction Plastically deformed cable, deformation wave one-diameter period propagates on ~6 innermost turns in the spool Reacted cable does not fit into the structure groove	Strands sintering, no oil applied, Mica insulation is too short (15 mm) Build up of the compressive strain in the turns due to rigid spools, which can not relatively moved Difference in thermal expansion for the core material and the cable Cable size grow after reaction	Reduce thickness of ground insulation by 10mil	Cable oiling, used wide 22.25mm Mica tape Last turn supported by several copper strips distributed on the spool circumference Produce ~0.5-0.7mm gap between the core and innermost turn before reaction New cable size 21.79x1.259mm (22.25x1.28), 59 strands instead of 60
Cable insulation	B-stage glass tape have been broken twice on one tensioner	Big tension of 30lb applied on more rigid component	Fill gaps by additional tape glued to the Kapton	Check tension, the same
Ground insulation	Kapton 2x5mil insulation (used instead of G10 strip) wrinkled during winding	Not rigid enough		Use G10 strips
Metal shims	Big width, electric short, last coil's turn deformation	Bended edges due to un proper pack insertion Bed edge trimming		Need revision, change metal shim to G10 one
Laminated packs	Hard to insert	Sharp edges on the lamination's legs		Edges chamfering
End parts	Applying pressure	Not enough screws, may be need additional tooling		
Rods	Do not fit in the pack's hole	Wrong rod diameter		Reduce rod's or increase hole's diameter
Tubes	Do not fit in the pack's hole	Laminated structure distortion due to fixture bending (bars)		Collaring fixture modification
Coil winding	One turn less on the first block (-18mil)-17 turns Two turns less for the second block-20 turns Right number of turns for third block-18 turns One coil is more dense Cable collapsing Shorts checking	Lose winding without compression, weak C-clamps, cable size by ~1 mil larger measured one, wrong insulation schema Cable was compressed after each turn by hand and designed clamps have been used during winding Difference in cable and insulation tension Tensioner works not properly well Set of guided rollers have different height level	Roller's repositioning	Check cable size after reaction for right prediction of each block Tension calibration for cable and insulation New control boxes and instruction manual Insulation of the winding mandrel and the cable from the ground
Coil-to-coil splice	New design not finalized yet Cable collapsing before splicing	Eddy current losses in the existing design Unstable cable after reaction	Use old design Adhesive scotch tape placed on the cable	Design modification, two peaces of 41 strand race-track cable in copper stabilizer The same
Lead splice	Require 2x0.5m 60 strand NbTi cables	For protection of Nb3Sn cable		Order placed at LBNL
Cable block transition	The cable located close to sharp edges of the end parts, may cause ground shorts Strand's deformation wave propagates in the straight section	Small length of transition area, absent of the cable side insulation		Modification of the G10 spacers by making a groove as a guide
Instrumentation	Quench heater location Soldering of the voltage taps to the cable make cable more rigid for bending	Not checked in the TM		A sandwich design will be tested during tensioner checking before winding Minimize soldering to one strand area

Table 3. Lessons from the Technological Mode

Cable.

The cable for the magnet was made of 59 Nb_3Sn (60 for TM) strands with 0.7 mm diameter. The strands were produced by the Oxford Superconducting Technology (OST) using MJR process. Two pieces (144-m and 120-m long) of 22.78-mm wide and 1.25-mm thick cable were fabricated at LBNL. Final cable dimensions for the magnet were reduced by ~2% based on experience of TM production. The cable specifications are shown below in Table 4.

/ Magnet

CABLE No.	R4O-B0840, 841, 842
Mfg Date:	7/16/02
OPERATOR:	Giorgio Ambrosio, H. Higley, Evan Palmerston.
Rev.	7/17/02

CABLE LOG SHEET
LBNL-SUPERCON-AFRD
SUPERCONDUCTING MAGNET CABLES

Objective : Manufacture 60 or 59 strand cables for FNAL CCRW cabling program.
With reduced width from 22.25mm to 21.75mm

- STRAND INFORMATION -

MANUFACTURER :	Oxford ORE		
BILLET #:	ORE- 152, 159, 164, 166, 192, 193, 194		
SPOOL #:	See strand map " stmpR4-O-B0840_41_42Ore152_64_66_92_93_94.xls "		
COMPOSITION :	Nb3Sn		
STRAND Dia.. NOMINAL :	.7mm	INSP. DIA..:	.70388mm average.
Cu/SC RATIO NOMINAL :		INSP. RATIO :	
FILAMENT TWIST/LENGTH :		DIRECTION :	Right hand
SHARP BEND TEST :			
LENGTH PER SPOOL :	157m / 135m with tube joints. See strand map.		

NOTES: Strand inventory and unit length divisions provided by Giorgio Ambrosio.
All strand spools were placed on the cabler in clockwise order from 1 to 60. Strand #1 was intermittently marked with green permanent marker. This means that viewed from the point end of each cable the order will be 1-60 clockwise consistent with the strand map.

- CABLING SPECIFICATIONS -

TYPE or SPEC.:	FNAL CCRW Type 4 (was 60 strand x 22.25mm) modified to (59 strand x 21.75mm)				
No. of STRANDS:	59 strands a small sample of 60st at this width was made at the start and end of run.				
PITCH DIRECTION:	LEFT	PITCH LENGTH:	Set at 145mm measured at 139mm.		
PLANETARY RATIO:	-.57:1				
ROLLER ID #:	P 41 & 42	WIDTH:	**21.689**mm	ANGLE:	0
MANDREL ID #:	41	WIDTH:	21.35mm	THICKNESS:	.63mm
LUBRICATION :	4BR + 5% MOBIL-1 ~5-6 drops/pitch length.				
STRAND TENSION:	2.5 kg. +/- .05	TURKS HEAD LOAD "SGM":	-127 kg.		
Nom. THICKNESS:	1.255mm				
Nom. WIDTH:	21.75mm				
Nom. ANGLE:	0				

- FINISHED CABLE -

	R4O-B0840	R4O-B0841	R4O-B0842
No. of Strands :	59	59	60
FINISHED LENGTH:	144.5m	120m	6m
Avg. THICKNESS:	1.259/1.244	1.259/1.244	
Avg. WIDTH:	21.79/21.78-		
Avg. ANGLE:			

RESIDUAL TWIST/Mtr.:	Nearly flat slight under twist.
ETCH for FILAMENT DAMAGE:	No evidence of filament damage see photo: R4O-B0840-Etched-01 & 02 .JPG

NOTES: A 0.5m sample of 60 strand cable was made first at a lower strand tension of 2.25 kg. The edges looked over compacted. We decided to drop one strand to 59 strands and increase strand tension to the

Table 4. Nb_3Sn cable parameters.

LBNL also produced NbTi 50-strands cable for magnet connection to the current leads. See a spec below in Table 5.

Leads NbTi

CABLE No.	S/C 861
Mfg Date:.	1/07/03
OPERATOR:	H.Higley
Rev.	1/07/03

CABLE LOG SHEET
LBNL-SUPERCON-AFRD
SUPERCONDUCTING MAGNET CABLES

Objective : Mfg. 19m NbTi leader material for FNAL CCRW magnet program.
To be used as leader material. For FNAL magnet.

- STRAND INFORMATION -

MANUFACTURER :	Teledyne		
BILLET #:	3-T-00066-A-04		
SPOOL #:			
COMPOSITION :	NbTi		
STRAND Dia.. NOMINAL :	.808mm	INSP. DIA..:	.807nn
Cu/SC RATIO NOMINAL :	1.31:1	INSP. RATIO :	
FILAMENT TWIST/LENGTH :		DIRECTION :	Right
SHARP BEND TEST :			
LENGTH PER SPOOL :	30m		

NOTES:

- CABLING SPECIFICATIONS -

TYPE or SPEC.:	Prototype leader material for FNAL CCRW program					
No. of STRANDS:	50					
PITCH DIRECTION:	Left	PITCH LENGTH:	~150mm			
PLANETARY RATIO:	-.57:1					
ROLLER ID #:	P40 & 41	WIDTH:		ANGLE::		
MANDREL ID #:		WIDTH:		THICKNESS::		
LUBRICATION :	4BR drip.					
STRAND TENSION:	5.25 lbs/	TURKS HEAD LOAD "SGM":				
Nom. THICKNESS:						
Nom. WIDTH:						
Nom. ANGLE:						

- FINISHED CABLE -

	861	
FINISHED LENGTH:	19m +	19.5m (64' 5")
Avg. THICKNESS:	1.34mm	[redacted] 1.38mm
Avg. WIDTH:	22.1mm	[redacted] 22.0mm
Avg. ANGLE:		
Cable/Strand Yield:		

RESIDUAL TWIST/Mtr.:	< 90 / m
ETCH for FILAMENT DAMAGE:	

NOTES Cable measuring machine not used. Estimated packing factor = 90%

Table 5. NbTi cable for current leads.

A racetrack Nb_3Sn 41-strands cable was used for the internal splice of two coils. A conductor specification is listed bellow in Table 6.

CABLE No. **FNL R&W-R1O-00811**
MFG. 8/01/01 LBNL
OPERATOR: H.Higley, E. Palmerston

CABLE LOG SHEET
LBNL-SUPERCON-AFRD
SUPERCONDUCTING MAGNET MATERIALS
BLD 52

Objective:

1) **Nb3Sn 41 strand cable Identical to LBNL Cable # R1I-00799 using Oxford strand**

- STRAND INFORMATION-

MANUFACTURER :	Oxford		
BILLET #:	Ore-151 & Ore-152		
SPOOL #:	See Respool Map. "stmpR1O00811_Ore151_152.x.ls"		
COMPOSITION :	Nb3Sn		
STRAND Dia.. NOMINAL :	0.7 mm	INSP. DIA..:	0.7034mm avg.
Cu/SC RATIO NOMINAL :		INSP. RATIO :	
FILAMENT TWIST/LENGTH :		DIRECTION :	Right
SHARP BEND TEST :			
LENGTH PER SPOOL :	150m, without leaders or trailers.		

- CABLING SPECIFICATIONS-

TYPE or SPEC.:	FNAL R&W -R1				
No. of STRANDS:	41				
PITCH DIRECTION:	LEFT	PITCH LENGTH:	110		
PLANETARY RATIO:	-.57				
ROLLER ID #:	P29 & 30	WIDTH:	15.006 mm	ANGLE:	0
MANDREL ID #:	39B	WIDTH:	14.32 mm	THICKNESS:	.58 mm
LUBRICATION :	MOBIL-1, 5% + Naphtha as thinner, approximately 1.5 drop/ pitch.				
STRAND TENSION:	2.5kg. +/- .1	TURKS HEAD LOAD "SGM":			

- FINISHED CABLE -

	R1O-00811
FINISHED LENGTH:	141m
Avg. THICKNESS:	1.2230 mm
Avg. WIDTH:	15.0714 mm
Avg. ANGLE:	-0.028 deg.
RESIDUAL TWIST/Mtr.:	90 deg. under twist "good direction"
ETCH for FILAMENT DAMAGE:	No damage, see photo.

Notes: This cable looks very good. It has a very uniform surface finish and minimal residual twist.
This cable is slightly wider than cable #R1i-00799, probably due to the decreased Cu content in the Oxford strand. The same increase in width was not measured for the 60 strand cables #802 & 803 because the cable measuring machine was not used.

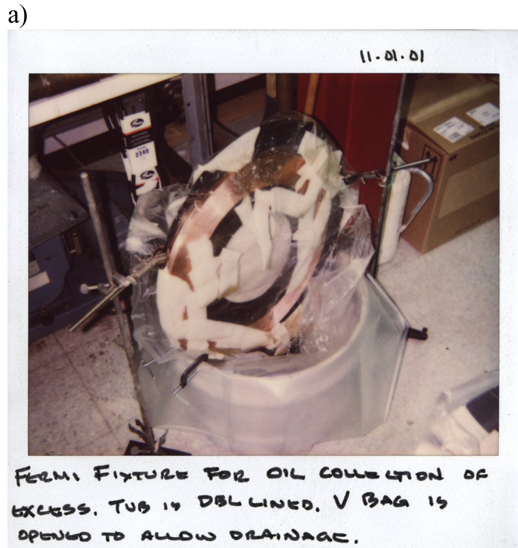
Table 6. Cable for internal splice.

Cable Preparation for Heat Treatment

Mobil oil inside of the cable prevents strand sintering during cable reaction. Mobil 1 formula 0W-30 was used because it has the lowest viscosity (53 cSt at 40 C and 10 cSt at 100 C) among Mobil 1 oils.
The content of synthetic oil was increased according to the following procedure.

Cable preparation:
- wind each cable on a metallic spool,
Oil "impregnation" (performed at the Material workshop):
-each cable was 'impregnated separately' in a plastic bag (polyethylene 5 mil thick) with two ports (one for vacuum, one for oil inlet)
- de-gas the oil (about 2 liters per bag),
- make vacuum and let it run overnight,
- slowly input the oil in the bag,
- stop when the spools are completely filled by oil (when there are no difference between inner and outer pressure),
- wait a few hours for a uniform distribution of the oil in the bag,
- close vacuum pump (actually we had to close it a few minutes after impregnation start because it was pumping oil),
- heat up the spool (100 C for 3 hours).
Cleaning:
-make the spool stand in vertical orientation above the tank in order to let the extra oil drip in the tank,
- remove the cables form the spools and clean them with wiping rolls a paper,
- clean the spools,
- dispose oil and papers.

a)



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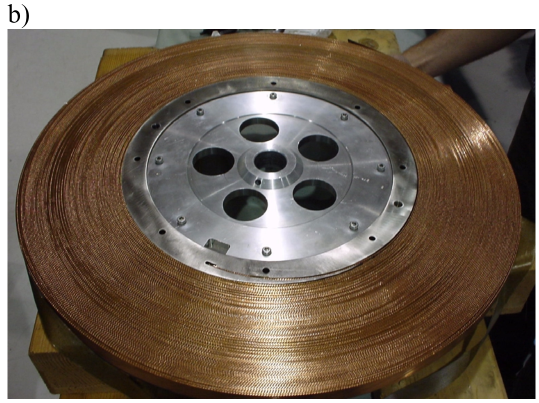


c)

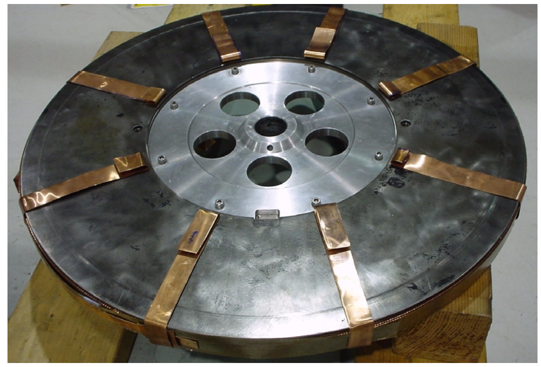
Figure 3.
a) - Set up for cable impregnation with oil;
b) - Oil drainage
c) - Cable after oiling

Cable Heat Treatment

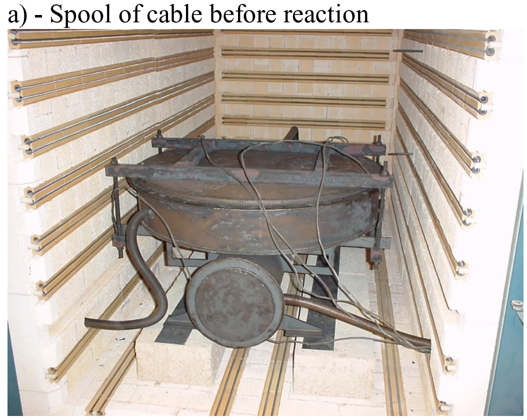
The cable for each coil was reacted on a single layer stainless steel spool inside the reaction retort. Two ~120-m long pieces of cable were wound on two metallic spools together with a mica-glass tape (Suritex 0822 0.1mm thick x 22mm wide x 50m from Electrolock Inc.) in order to prevent turn sintering during heat treatment.
The reaction spools had a diameter of 360 mm, which is two times larger than the minimum diameter in the coil at the ends. It minimizes the bending strain of the cable during winding. The retort was placed inside the big oven after welding of the cover plate. Vacuumed to 0.08Torr=10.7Pa.
The heat treatment suggested by the wire manufacturer (OST) performed in Argon atmosphere:
ramp at 25 C/h to the temperature of 210 C and hold for 100 h,
ramp at 25 C/h to the temperature of 340 C and hold for 48 h,
ramp at 25 C/h to the temperature of 650 C and hold for 180 h,
ramp down at less than 75 C/h.
For more details see appendix A.

There was a leak in the reaction retort at the top caver plate weld. As a result, a black residue appeared on the cable surface. Suppose it was an ash due to oil burning (tested as a good electric conductor).

Before and after the heat treatment there was a gap (about 2 mm maximum) between the innermost turn and the spool (Fig.5). The gap was removed by rotating the core of the spool in the direction opposite to the cable winding.



a) - Spool of cable before reaction

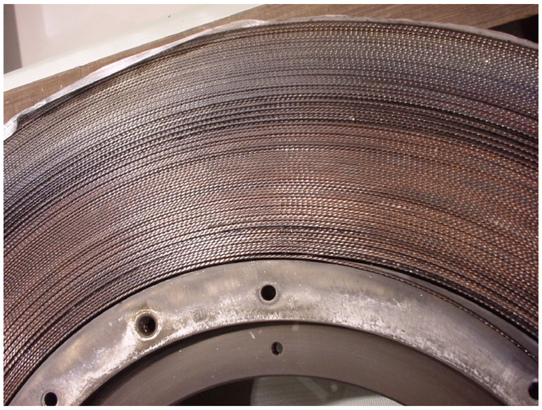


b) - Retort inside of the oven

c) - Retort leak

d) - Open retort after reaction

Figure 4.



a)

b)

Figure 5. a) - Gap (about 2 mm maximum) between the innermost turn and the spool
b) - Removing gap before winding start

Coil Internal Splice

Two Nb_3Sn cables had to be spliced before simultaneous winding of both coils into the support structure. Two U-shaped connectors joined the cable's ends (see Fig.6).

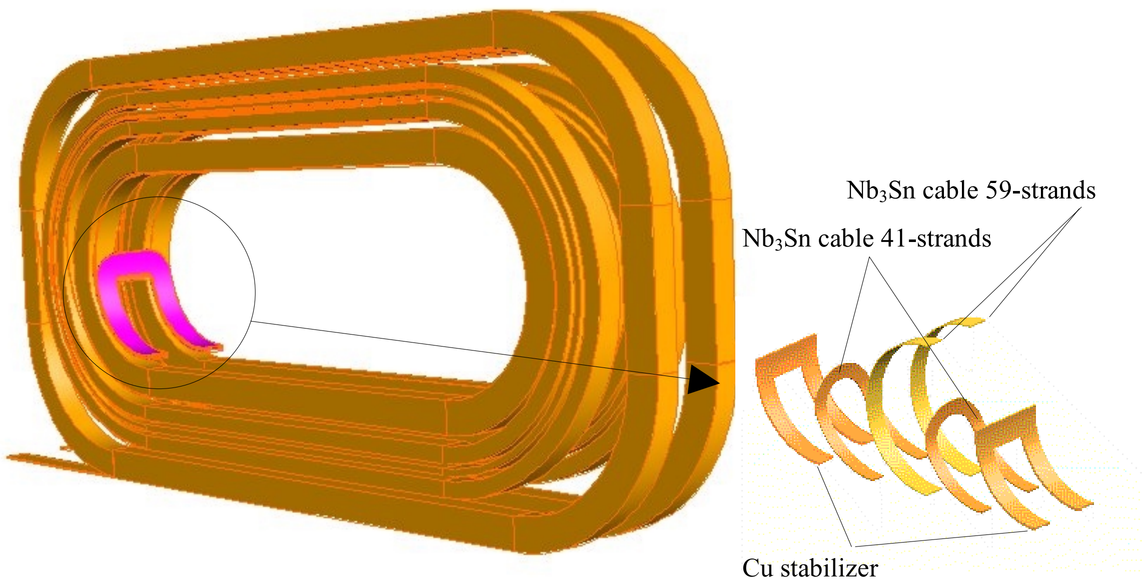
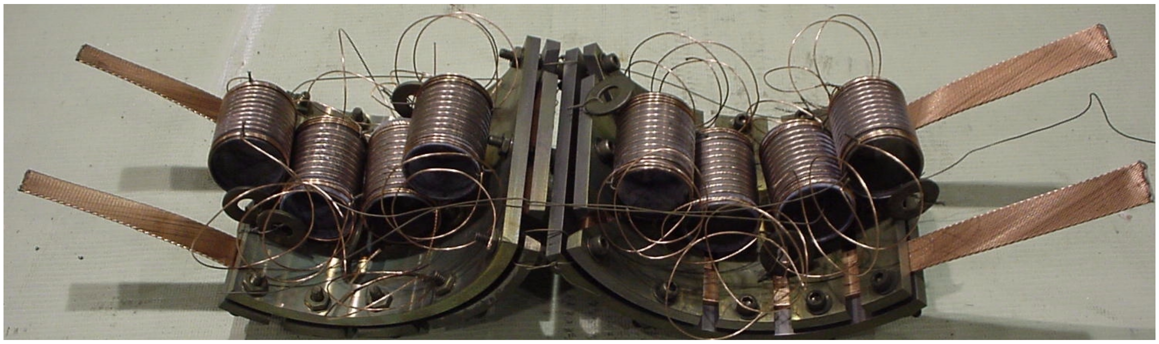


Figure 6. Coil internal splice

The 41-strand Nb_3Sn cable (racetrack version) was placed into the copper stabilizer using a special fixture and reacted together inside of the small oven. The heat treatment cycle was the same as for the coil conductor.



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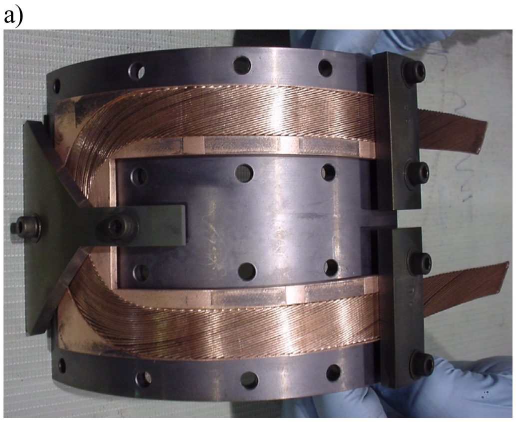

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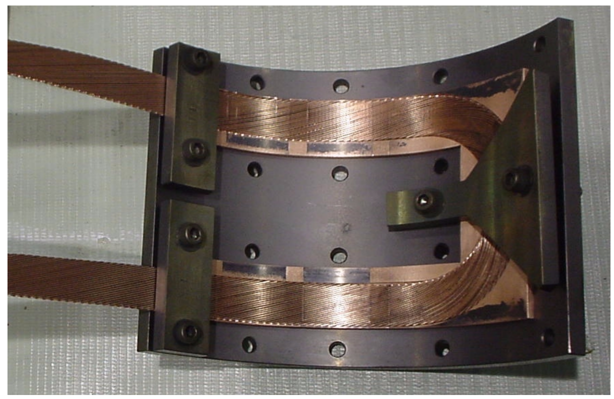
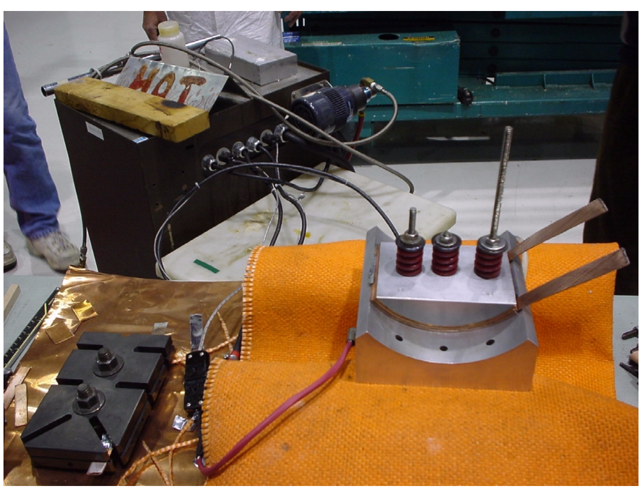


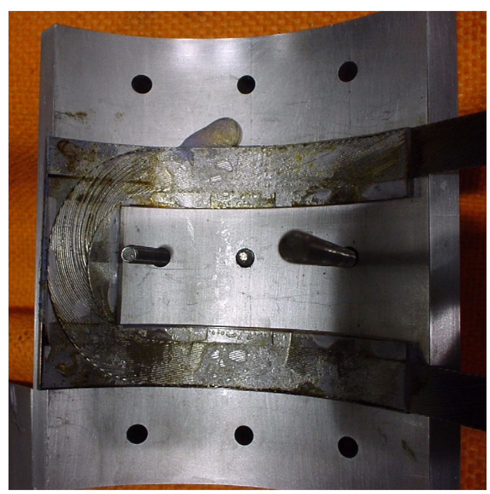
c)

Figure 7. a) - Splice reaction fixture and strands samples after reaction
b),c) - 41-strand cable in copper stabilizers after reaction.

Then the cable was soldered into the copper channel.

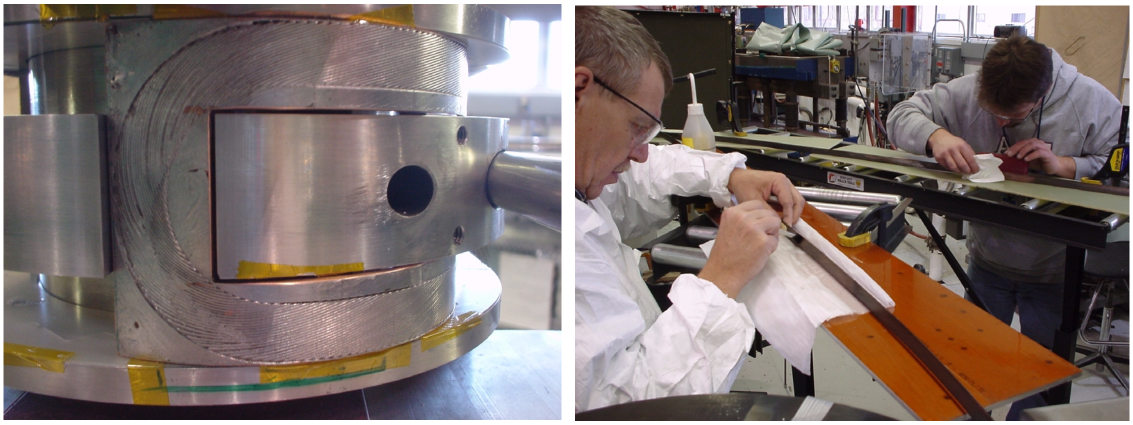


a)



b)

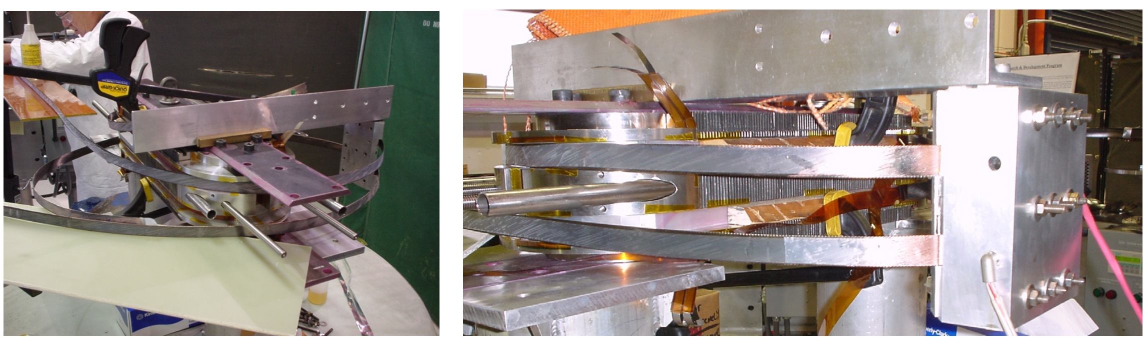
Figure 8. Soldering of the cable inside of copper stabilizer: a) - set up b) - after soldering



a) b)

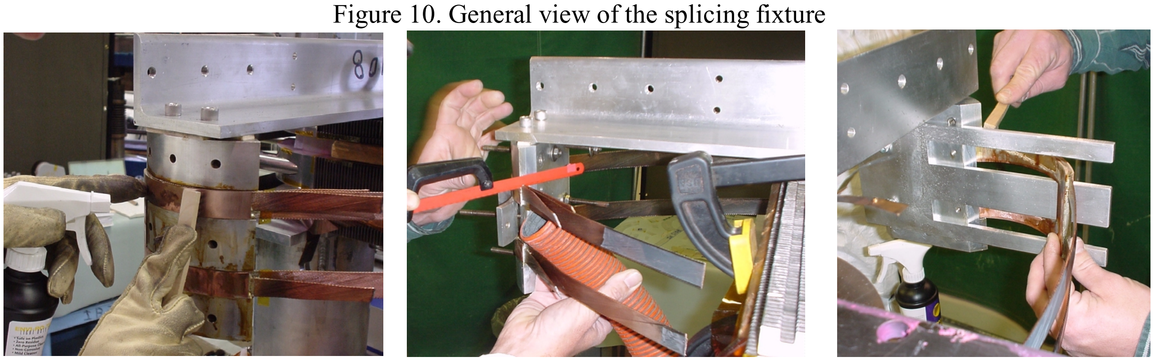
Figure 9. a) - Stabilizer inside a winding slot, b) - Cleaning of the cable splice area

The shape of the copper stabilizers was slightly modified before pre-tinning. It was done for easy splice fitting into an end part slot. A real splicing was made in a special fixture after several practice runs. The fixture has been vertically aligned with the winging grooves. Both cable spools were installed on two tensioners and approximately 4-5 first turns were un-wound. The spliced areas were carefully cleaned using alcohol. The cables were always supported and shape-protected. Scotch tape was applied to one cable side on the length from the spool to the mandrel. The splice fixture is shown in Fig 10-11. After soldering the splice was cleaned up and extra cables are trimmed out.



a) b)

Figure 10. General view of the splicing fixture



a) b) c)

Figure 11. a),c) - Splice cleaning, b) - Cable trimming.

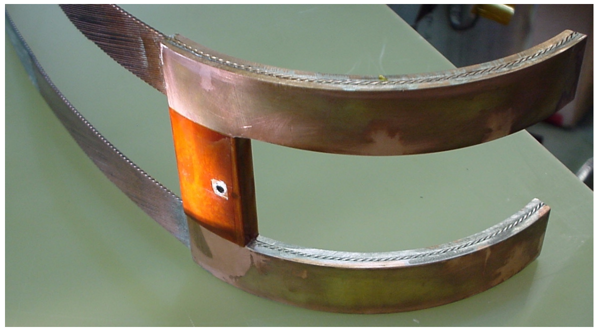


Figure 12. Splice final view

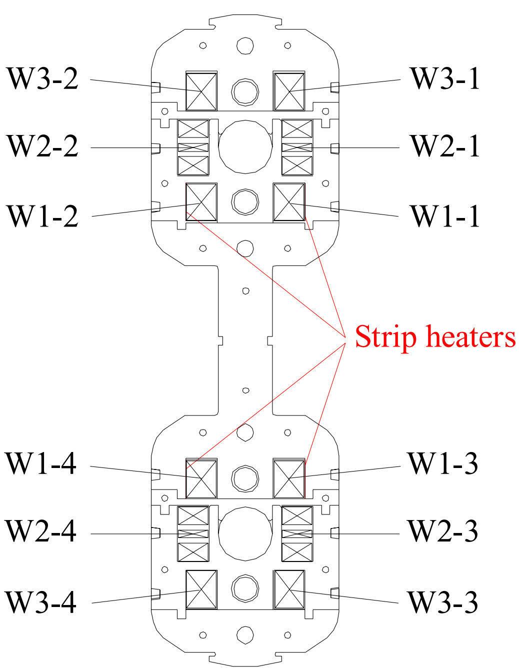
Cable Insulation

The cable insulation consisted of two tapes, ~6.5 mil pre-preg fiberglass tape and a 3 mil Kapton tape. The glass tape was pre-selected to reduce thickness variation (see TD-02-008 for more details). Both tapes had been spooled together on a single bobbin.

Strip Heaters

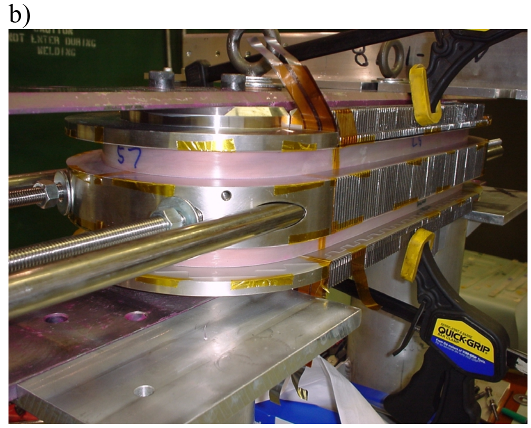
Four strip heaters were manufactured. The heater consists of 25umx10mm ss strip placed between 75um and 125um Kapton insulators. The heaters are located at the straight section of first 4 blocks as shown on Fig 13. Thinner insulation faced the coil ground insulation. The heaters in the magnet had a resistance of 2.3 ohm at room temperature.

Figure 13. a) and c): strip heater location b): strip heater view.



a)

b)



c)

Shim

A specially made shim replaced three stainless steel innermost spacers for the first conductor block. The shim purpose was to bridge all four transitions between magnet straight part and ends. It may protect the innermost coil turn from stress concentrations due to error in parts positioning.
The shim was made from un-reacted peace of Nb3Sn coil conductor, which had right thickness and easy to bend. The cable ends were pre tined and attached to the G10 spacers (with glue and G10 pin). The G10 spacers were placed around internal splice of the magnet coils.

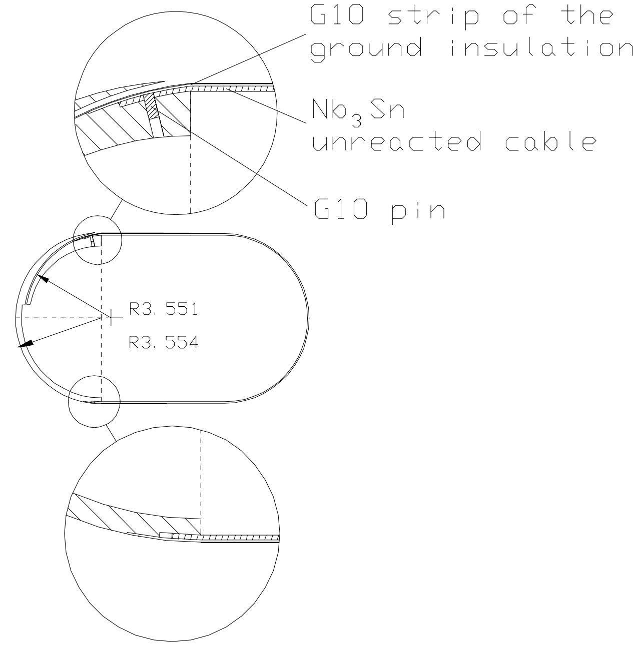
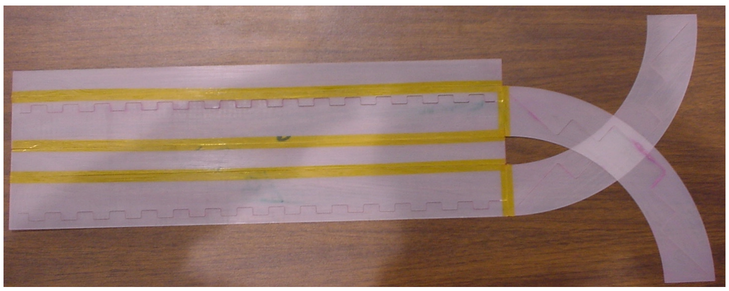


Figure 14. Shim layout.

Figure 15. Shim overview and cable-spaces attachmen

Coil Ground Insulation

Ideally, four 20mil G10 strips form a box-like insulation around the coil winding for each structural window. All strips are connected together by 1mil Kapton adhesive tape as shown on Fig 16. But in case of last block's turn and block transition turn, several layers of 5mil G10 strips are used instead of or in addition to 20mil strip. This allows convenient insulation staggering in the most complicated places. All strips were mold released on the outside surfaces.



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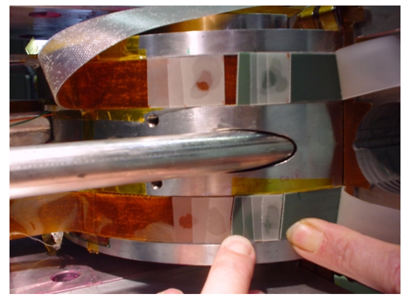

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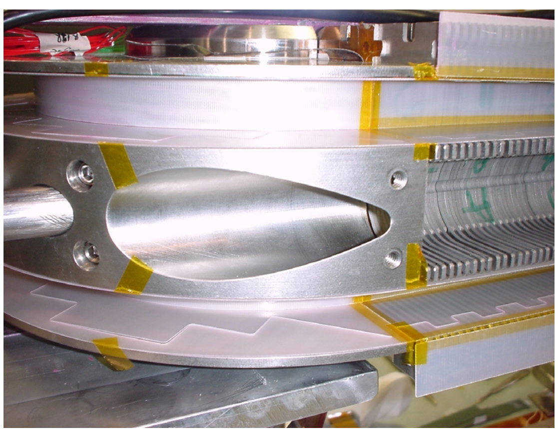

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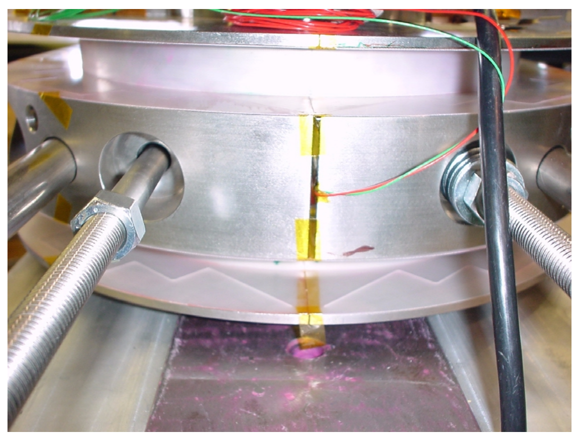


d)

Figure 16. a) Box-like ground insulation b) G10 strips covers last turn of the coil c) return end area of W2 d) instrumentation wires came from a epoxy channel on the return end.

Coil Winding and Instrumentation

The coil instrumentation is performed simultaneously with coil winding, since there will be no access to the coil after each block (W1, W2, W3) collaring. The coil ends are the only available location for comfortable wire attachment. There are total of 34 voltage taps (VT), 4 spot heaters (SH) and 6 temperature sensors (TS) installed on the coils (see Fig 17).

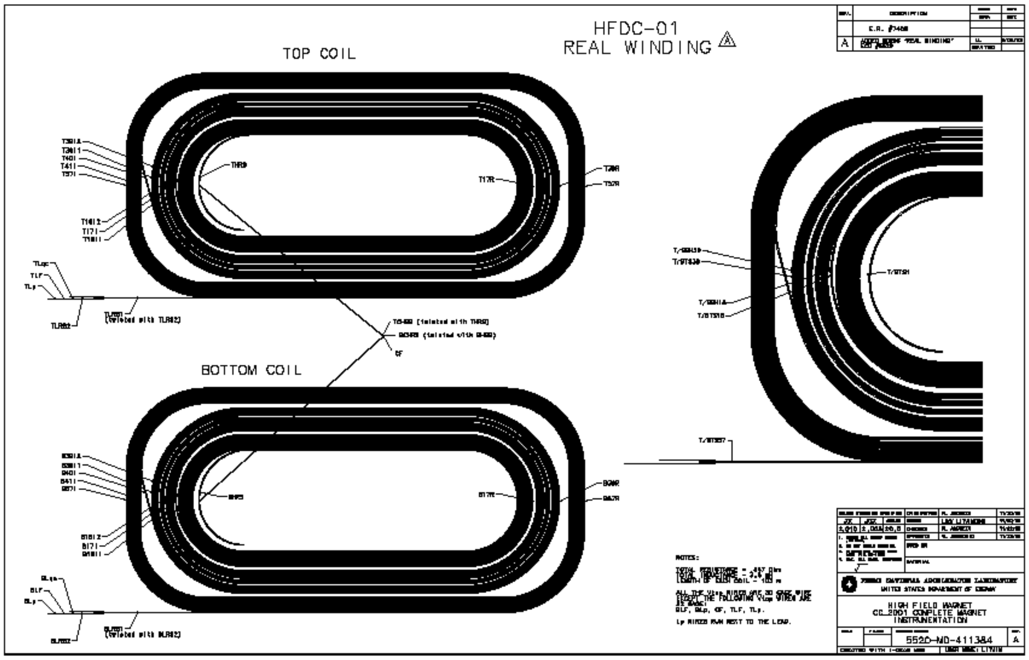
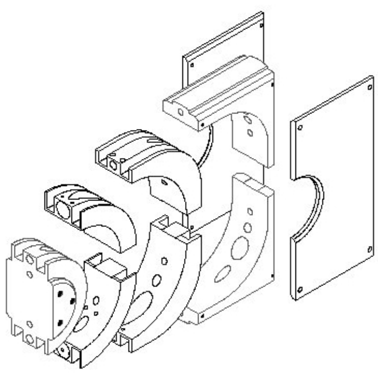
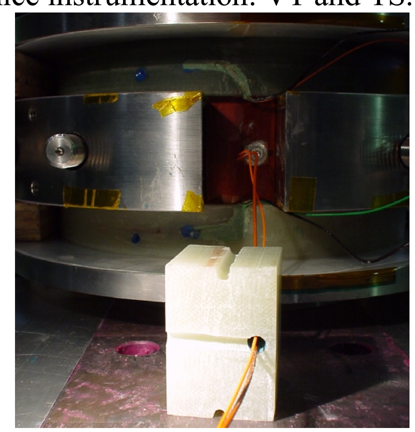


Figure 17. Coil instrumentation.

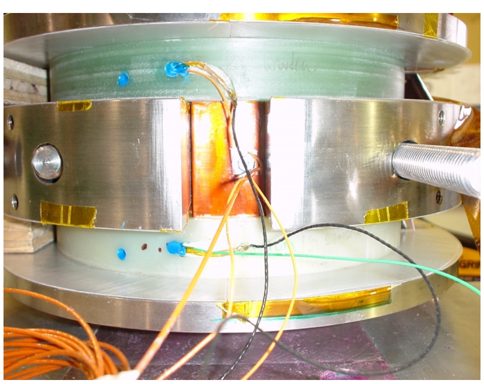
Following picture illustrated details of the internal splice instrumentation: VT and TS.



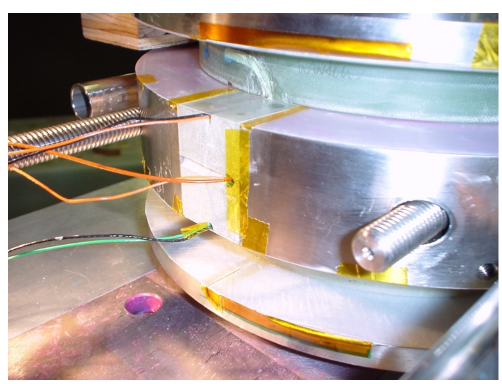
a)



b)



c)



d)

Figure 18. a) Return End metal parts, b) Filler, c) Instrumented G10 spacers covered the internal splice, d) Lead End before first turn winding

Four tensioners were used for coil winding, two for the cables and two for the insulations. The cable tensioners were modified after the technological model experience. Three intermediate wheels of the tension-controllers were removed and substituted with the same function motor-electronic scheme. The cable and the insulation now go under tension directly from the spool to the mandrel. This winding method was tested preliminary on the first window using a dummy cable.

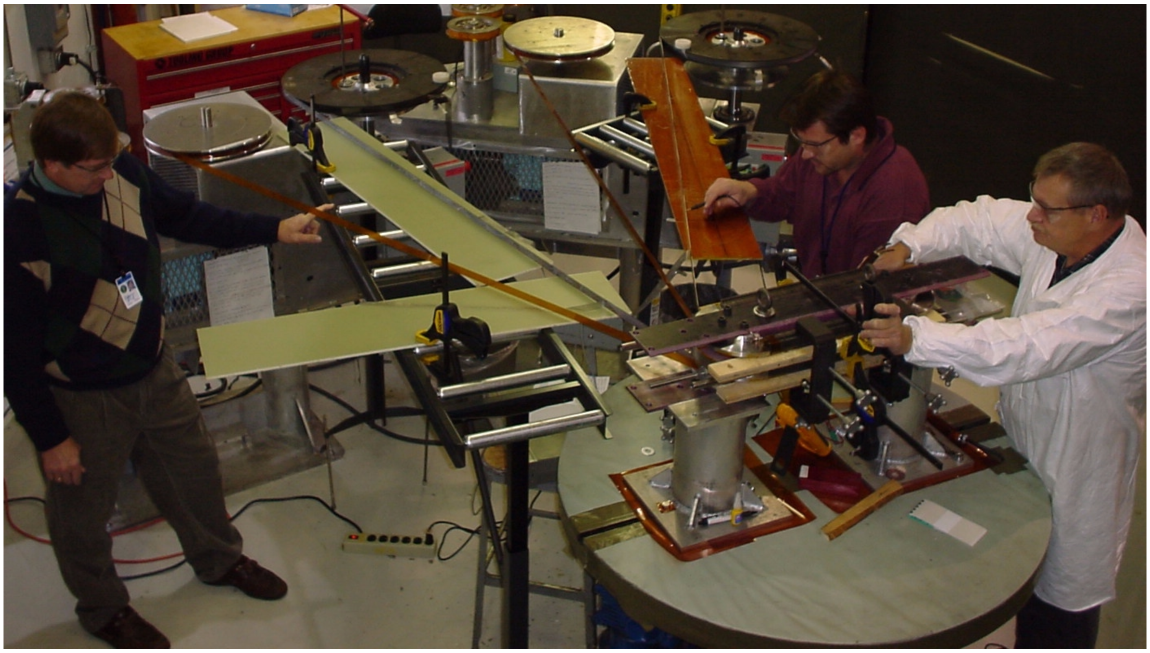
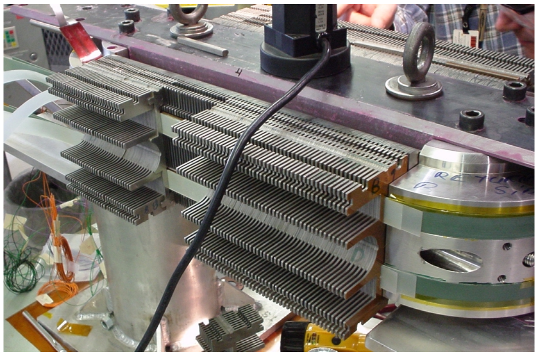


Figure 19. Coil winding

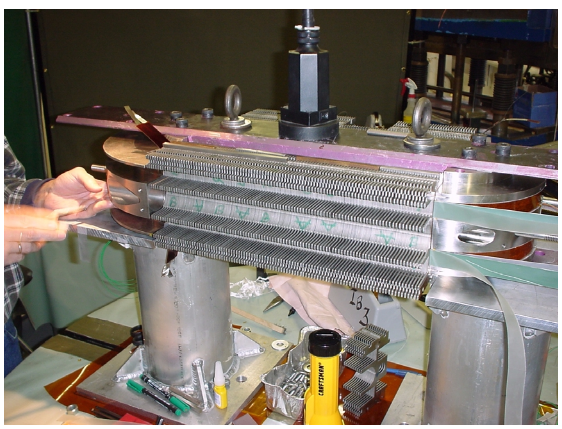
After internal splice installation and instrumentation, the first block of 17 conductors was wound with 30-lbs cable and 25-lbs insulation tension.
The situation during winding of turn #11 should be noted. The top coil cable was hooked on the corner of slightly shifted 20-mil G10 ground insulation (junction of the end and the straight section strips) and partially untwisted (~10^o). Tension was realized and the cable was normally shaped. The next half turn was wound without cable tension before applying full load again.
First block winding looks little bit fluffy. This can be explained by big cable thickness variation (see Fig. 29) of approximately first 8-10 turns.
To reduce a chance of cable damage due to collaring it was decided to wound one turn less than design geometry and fill in an extra space with 50mil G10 strip-fillers (2x20+2x5). Then the coil blocks were compressed in place by next sets of laminated packs using a “spider fixture”(see Fig 20). The packs were locked together by keys and with inserted tubes. Then the metal end parts compressed the coil ends by means of screws, rods and nuts.


a)


b)

Figure 20. a) Collaring of the first conductor block-W1, b) “Spider fixture” compressed the block W1

Next block ground insulation was installed into a new structural slot and a transition turn was wound. Each cable in the block transition area was instrumented with a VT, a SH and a TS. The end parts were slightly modified. Several grooves had been added for easy instrumentation wiring and all sharp edges were chamfered and insulated for avoiding of coil ground shorts.


a)

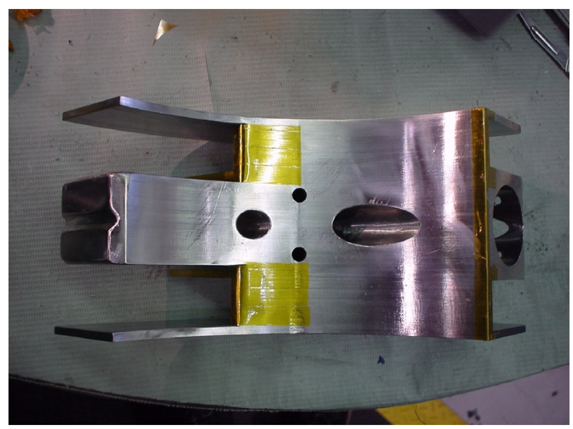

b)

Figure 21. a) Block W1 after keying b) Modified end parts before installation

Second and third conductor blocks were wound in the same way as the first one. Next three schemes show details for all coil blocks after collaring.

Figure 22.

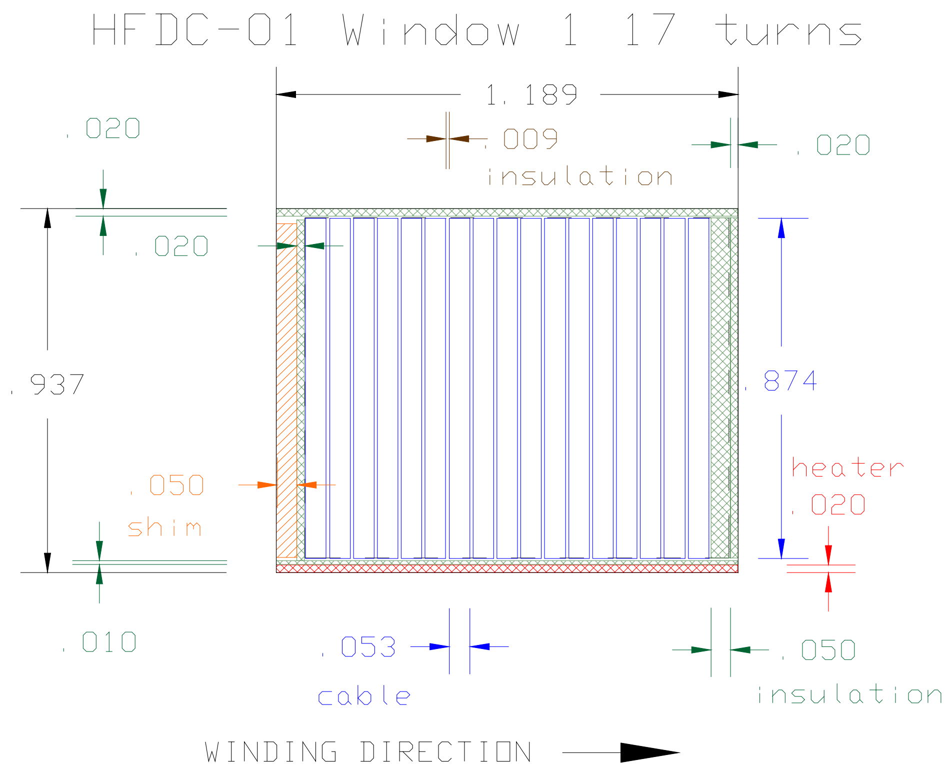


Figure 23.

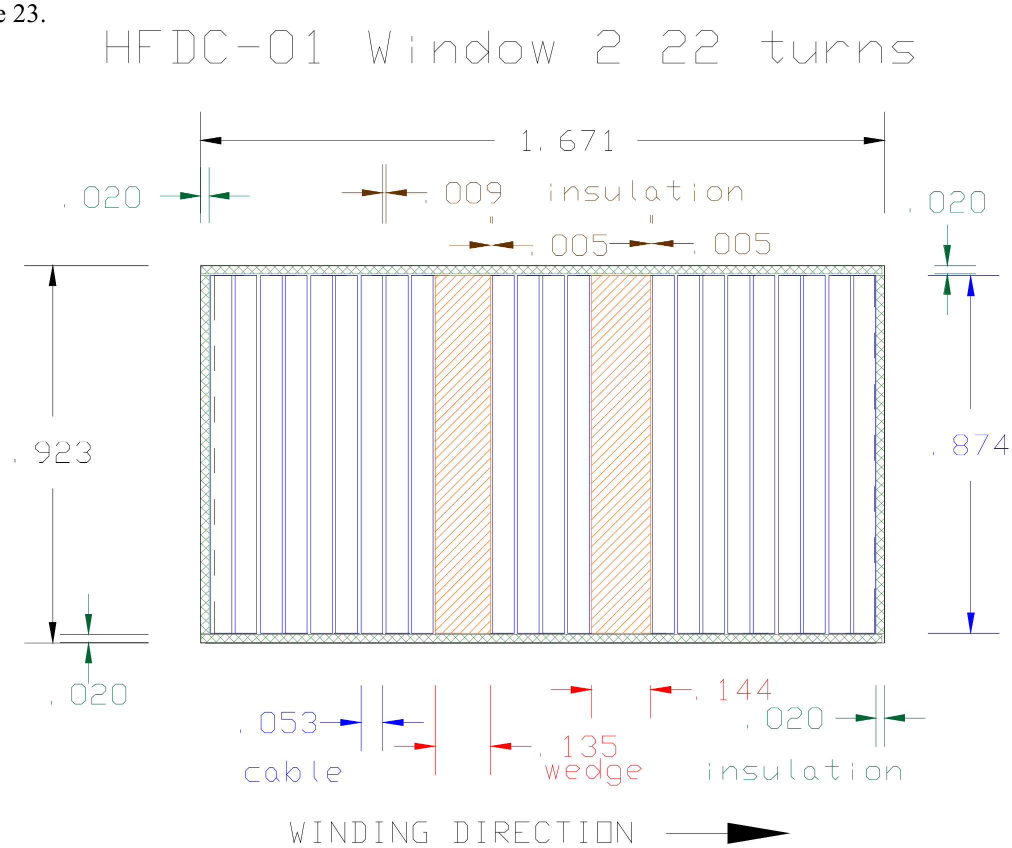
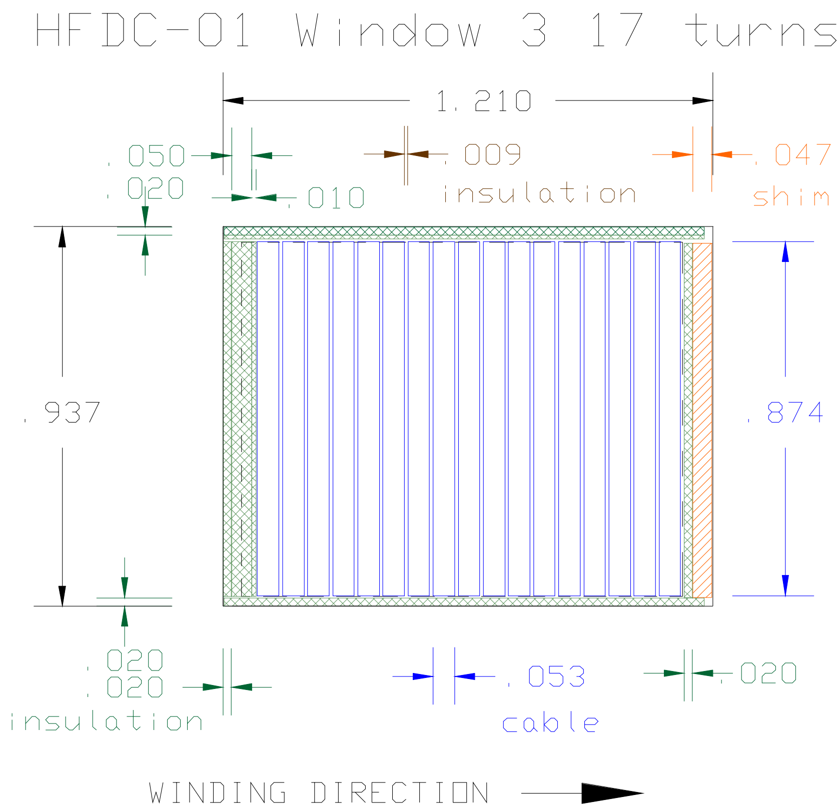


Figure 24.



Next several pictures show details of the block transition turns located at the lead end.

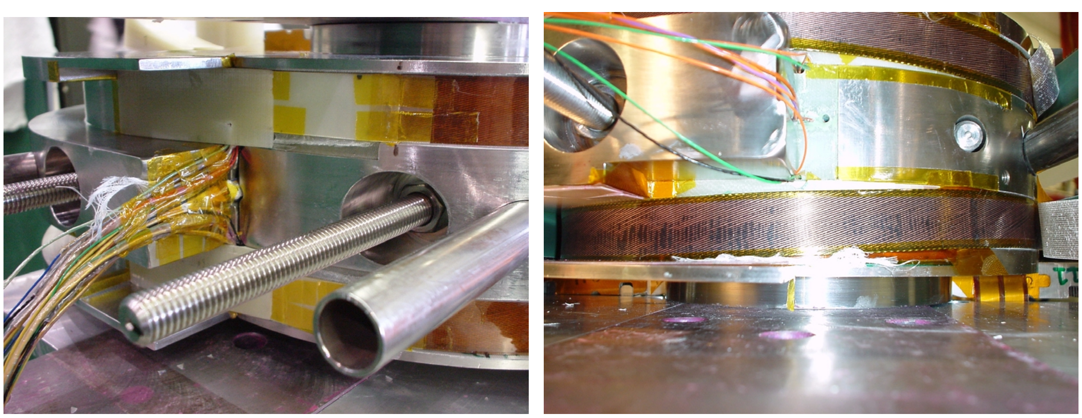
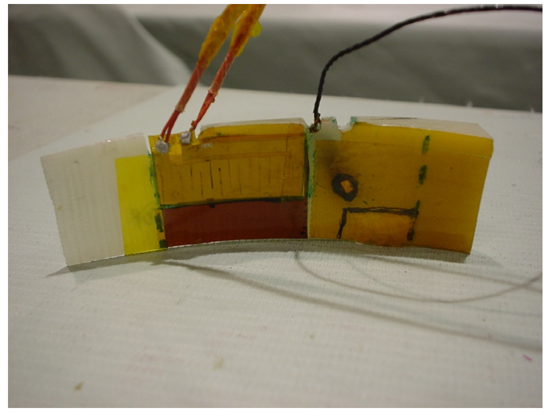
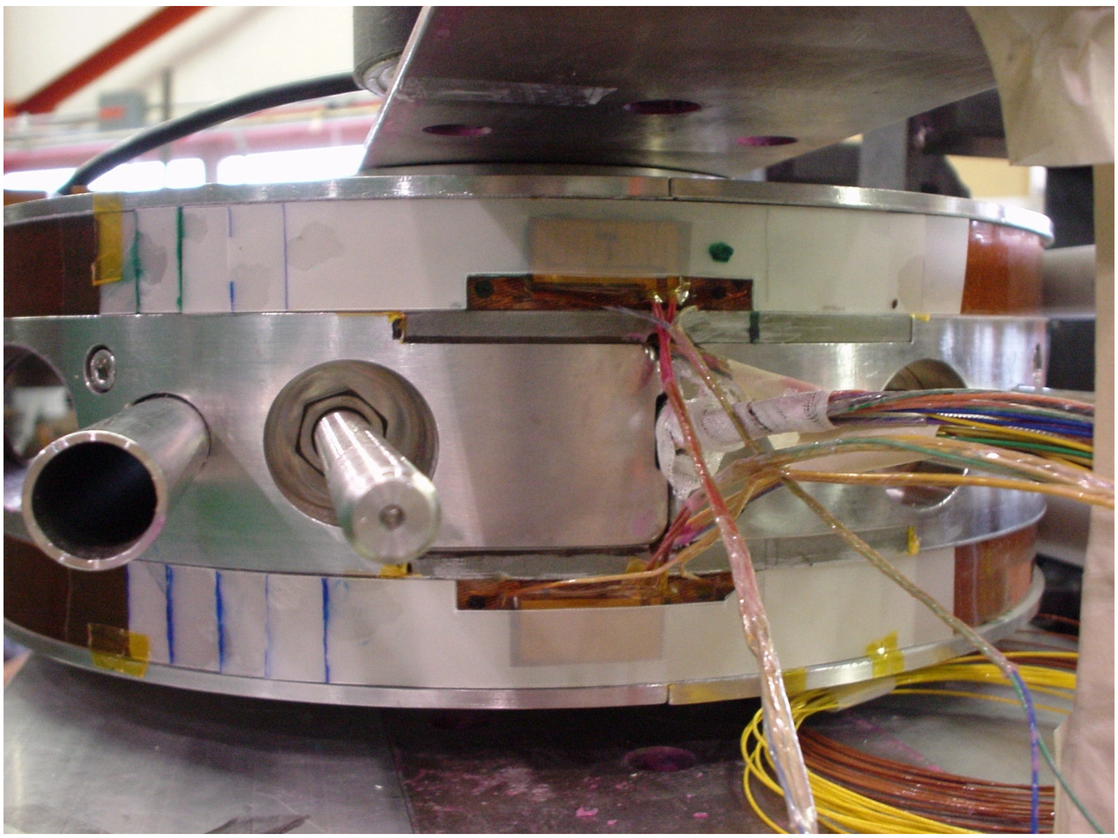


Figure 25. Details of the W2-W3 transition turn areas.

a)



b)



c)

Figure 26. a) Spacer with mounted SH and TS b) Instrumentation of the W1-W2 transition area c) Instrumentation of the W2-W3 transition area

The conductors were insulated from the ground and total winding resistance for each coil (from a magnet middle point) was measured as well as a cable and insulation thickness and cable width.

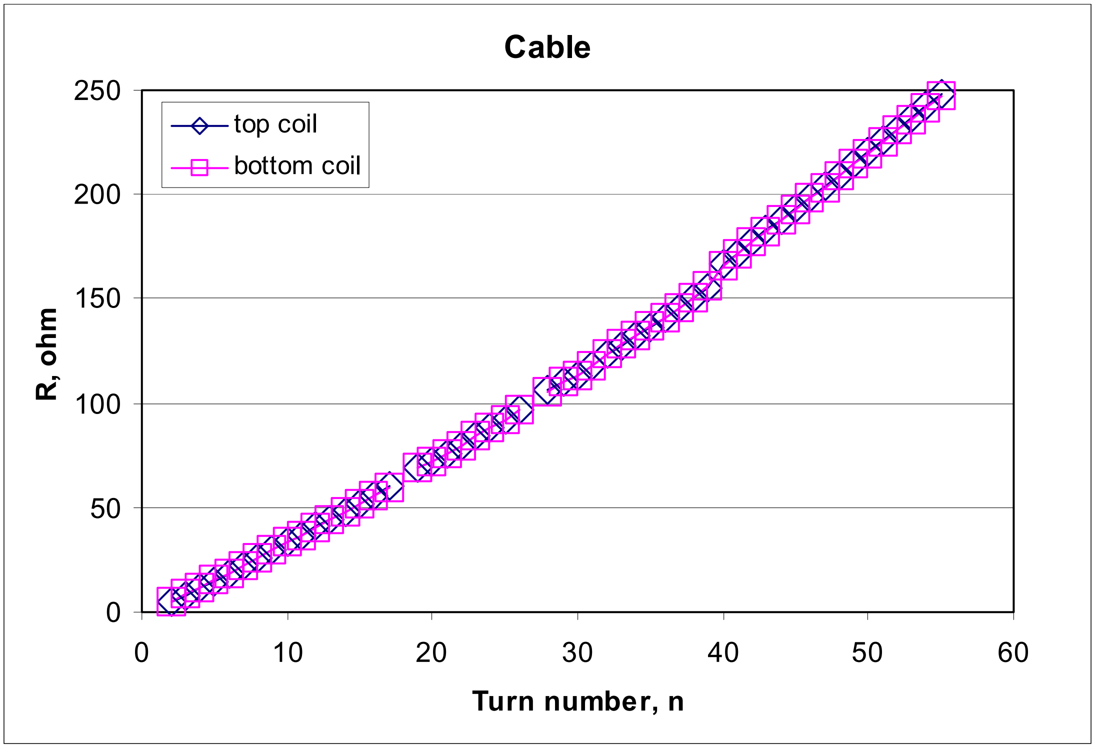


Figure 27. Coil resistance as function of coil turns.

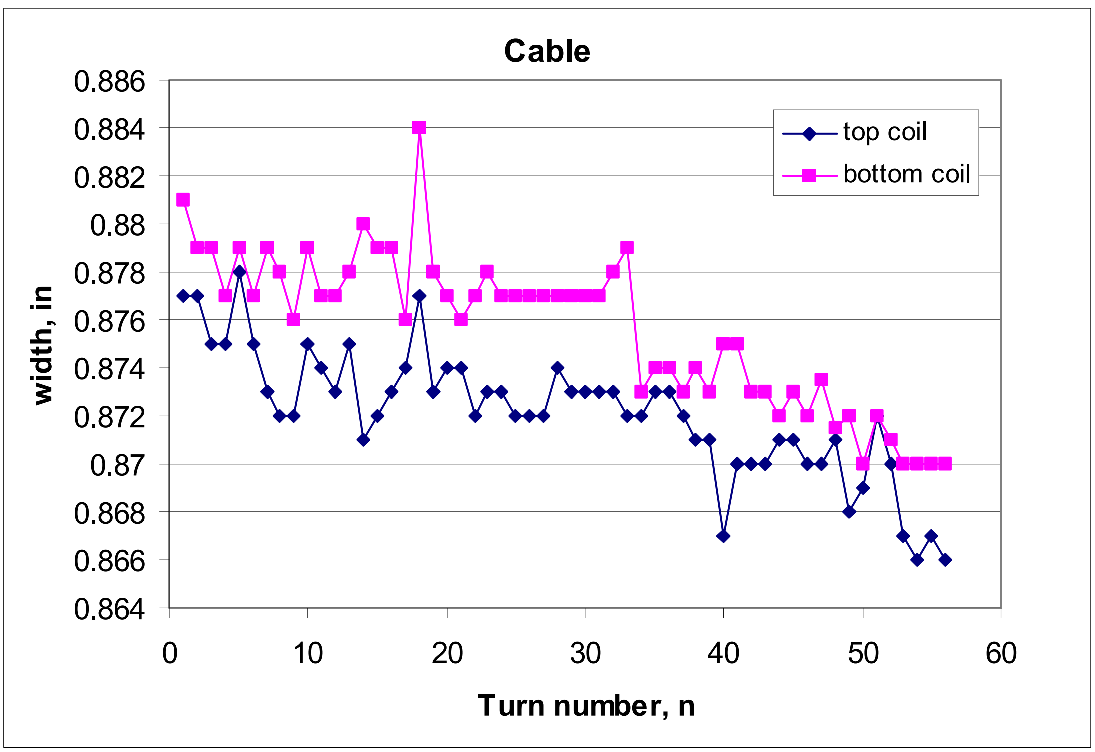


Figure 28. Cable width variation along the coil.

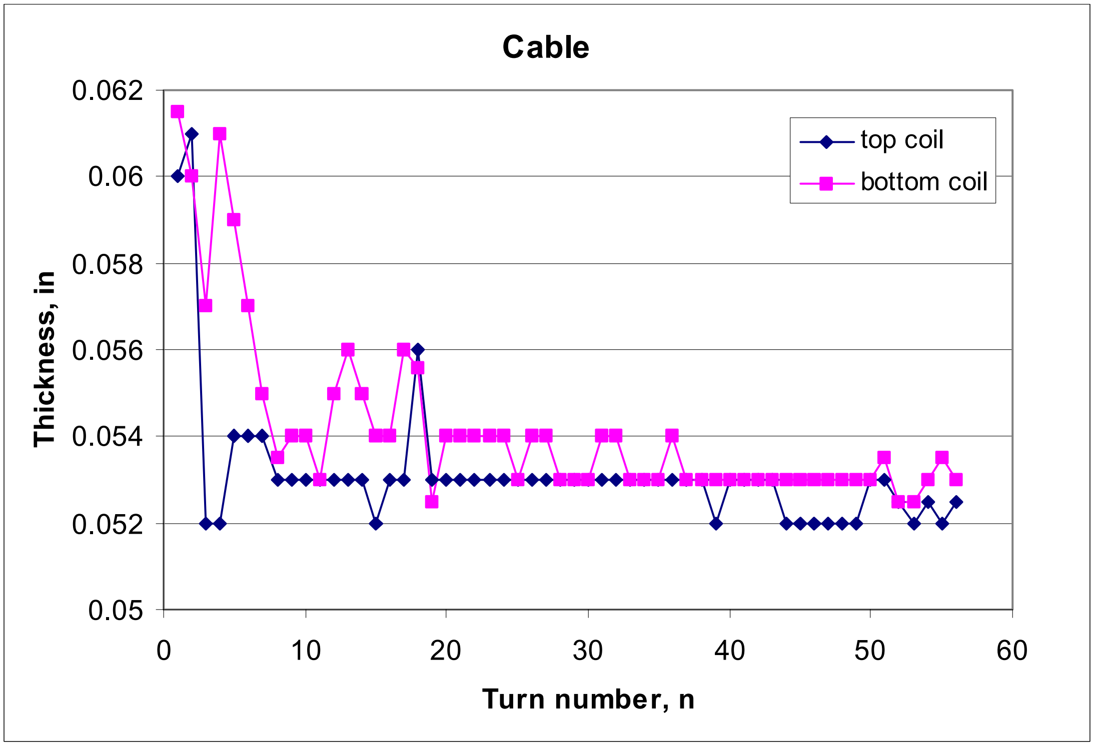


Figure 29. Cable thickness as function of coil turns.

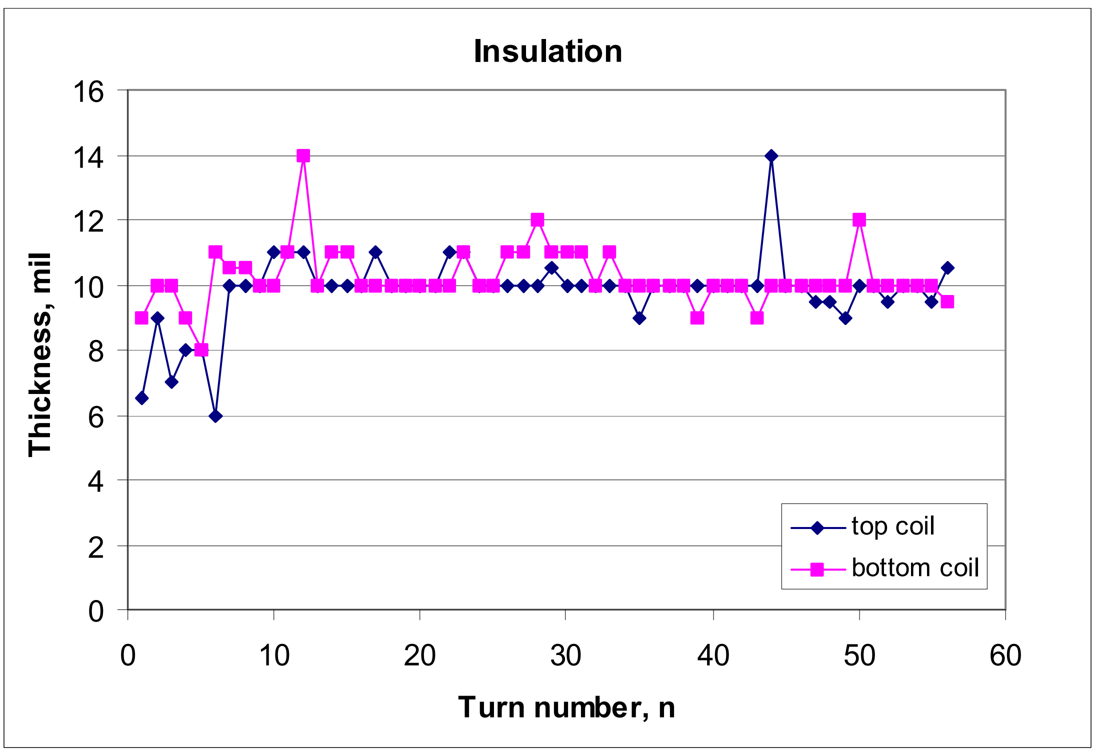


Figure 30.Variation of the cable turn-to-turn insulation along the coil.

Lead Splices

After winding, each Nb_3Sn lead cable was spliced with two NbTi cables and two stabilizing copper strips. The splicing procedure was identical to the lead splicing procedure developed for the racetrack models [3]. The 150-mm long splices were placed in the lead end block in such a way, which about a half of each splice was outside of the collared coil and will be in direct contact with liquid He, shown in Fig.32.

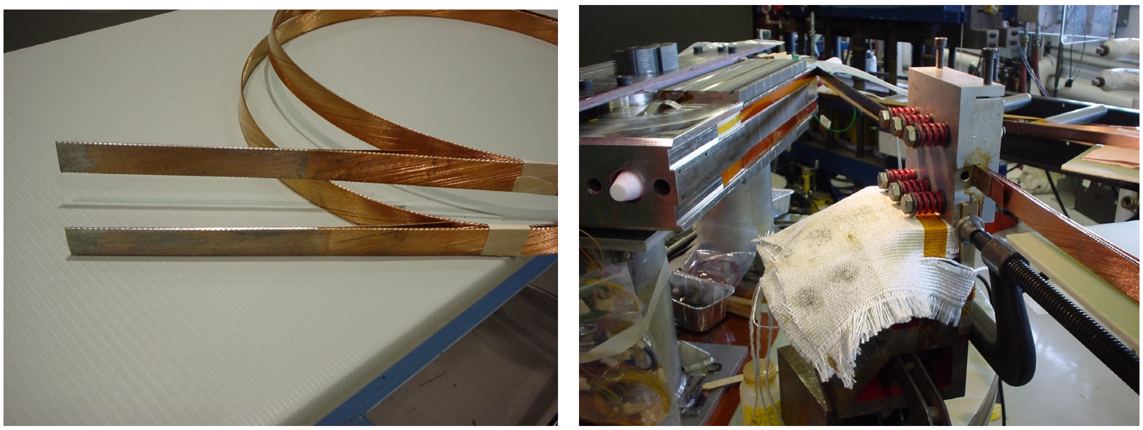


Figure 31. a) Pre-tined NbTi leads and b) Leads splicing.

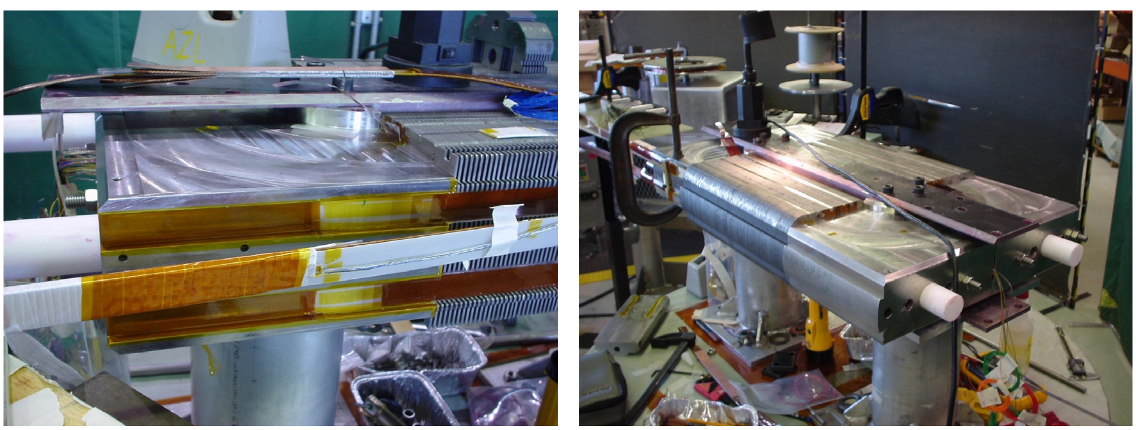


Figure 32. a) Insulated splice and grow, b) Final view after last turn packaging.

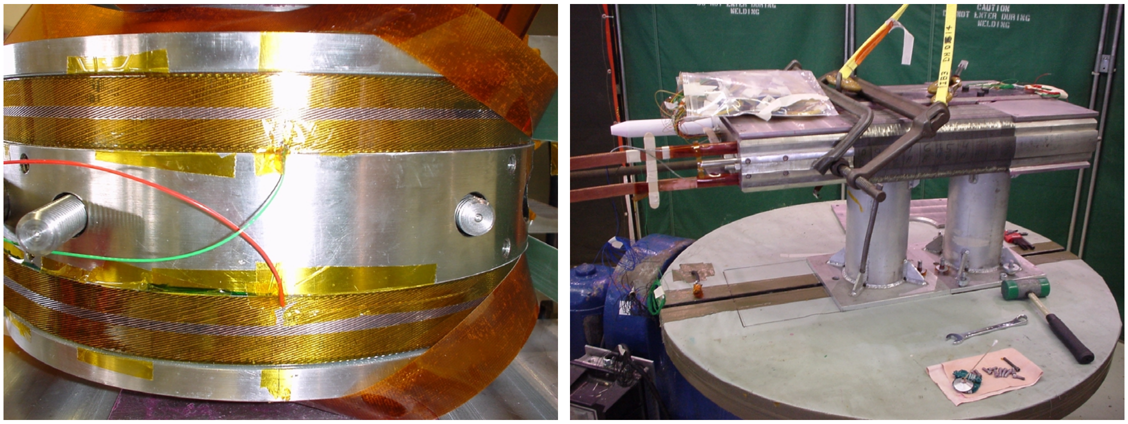


Figure 33. a) Last turn on the Return End, b) Lead End closing

Each splice area was instrumented with a VT and TS. The splice had been placed into structural groove after insulation as shown in Fig. Last set of the collar packs were inserted and keyed. Then a final cover block was installed on both leads together with the leads side plates.

Preparation for Impregnation

All internal cooling channels were closed by special plugs and sealed with red RTV. Entire outside surface of the coil block was mold released. The block placed into an impregnation fixture as shown on Fig 34-36.

Figure 34. Lead End and Return End of the collared coil before impregnation

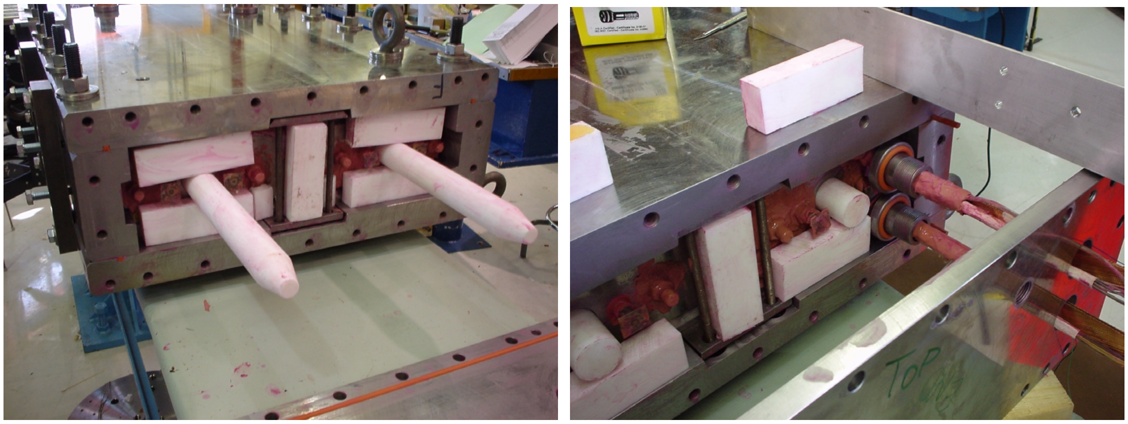


Figure 35. The magnet inside of the impregnation fixture

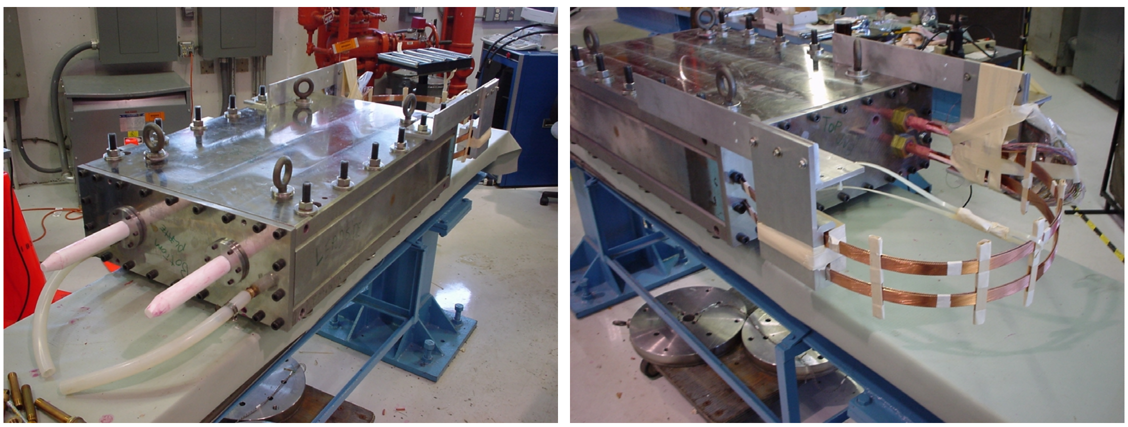


Figure 36. Impregnation fixture overview.

Coils Vacuum Impregnation with Epoxy

Time for pumping out - 66h
Vacuum- 23 um/Hg=0.023 mm/Hg= 0.023Torr= 3Pa
Epoxy: CTD 101
200 parts Resin, or part A – 20 kg
180 parts Hardener, or part B - 18 kg
3 parts Accelerator, or part C – 300 g
Mix at 60 C and pump down to 30-40 um/Hg during 40min for degassing.
Total time: 3h
Epoxy filling:
Flow meter is a glass tube 9cm long and 4.6mm in diameter
Flow rate: 1cm/sec for 7h and 3cm/sec for 2h
Total time: 9h
Epoxy curing in the Wisconsin oven:
Temperature 125C for 21h
Duration: 24h
Total time for vacuum epoxy impregnation is 5 days.

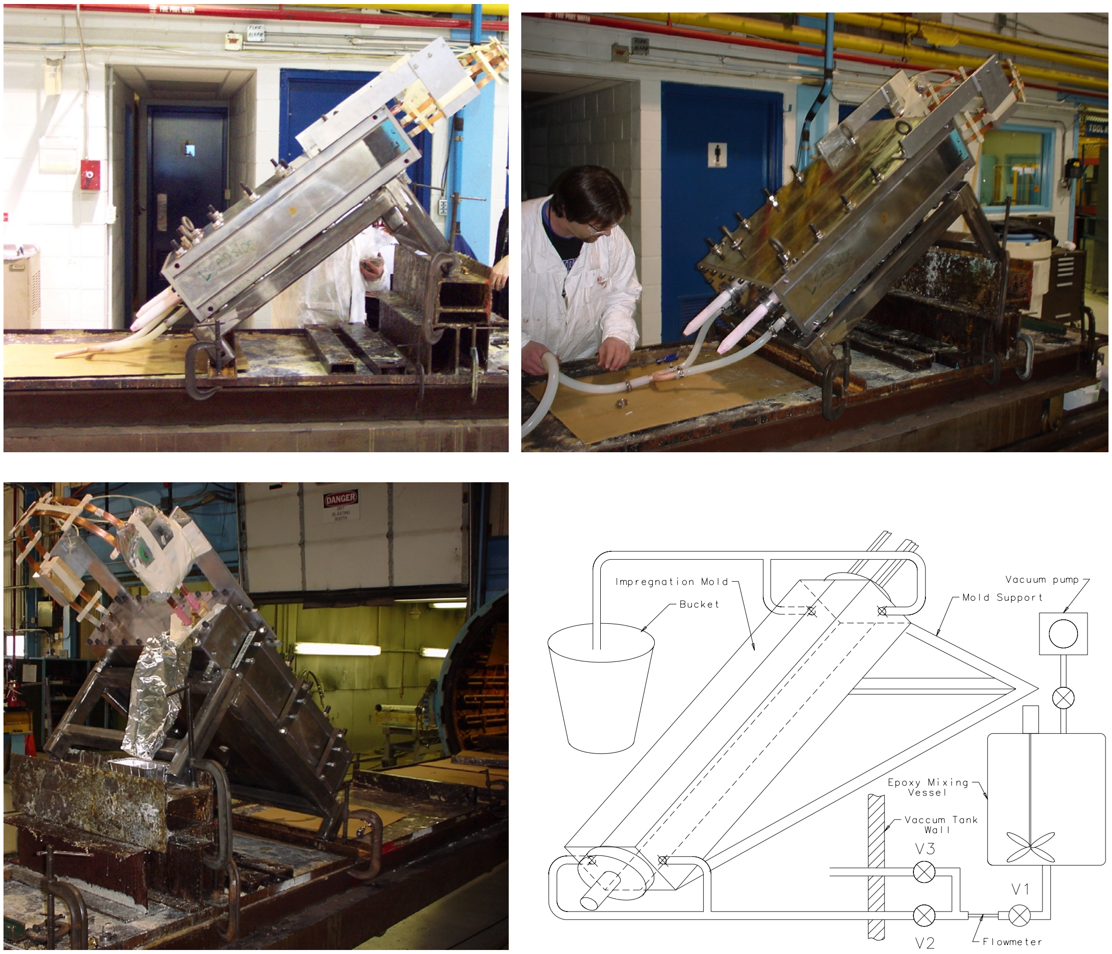


Figure 37. Epoxy impregnation set up

Post Reaction

The impregnation fixture was opened up and all surfaces were cleaned from epoxy. Also all side plats were removed from the ends and weld areas were cleaned up from epoxy.

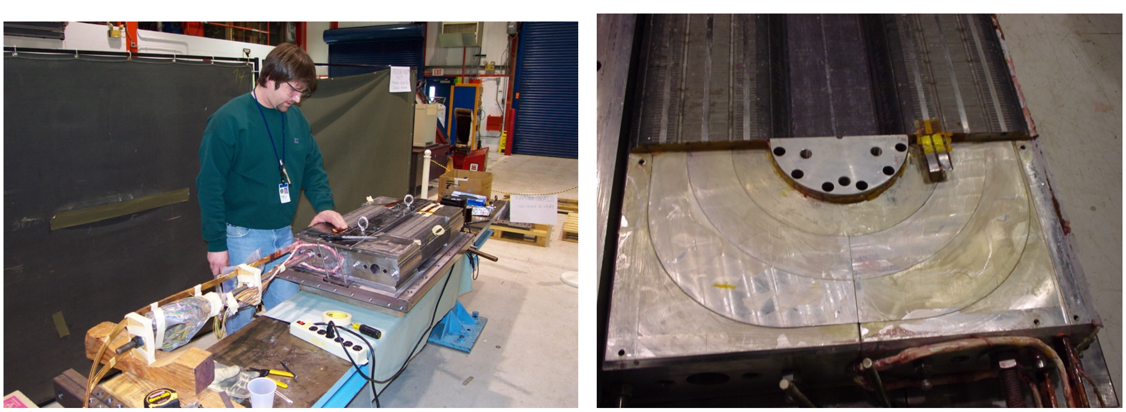


Figure 38. a) Block after cleaning, b) Lead End without metal side plate.

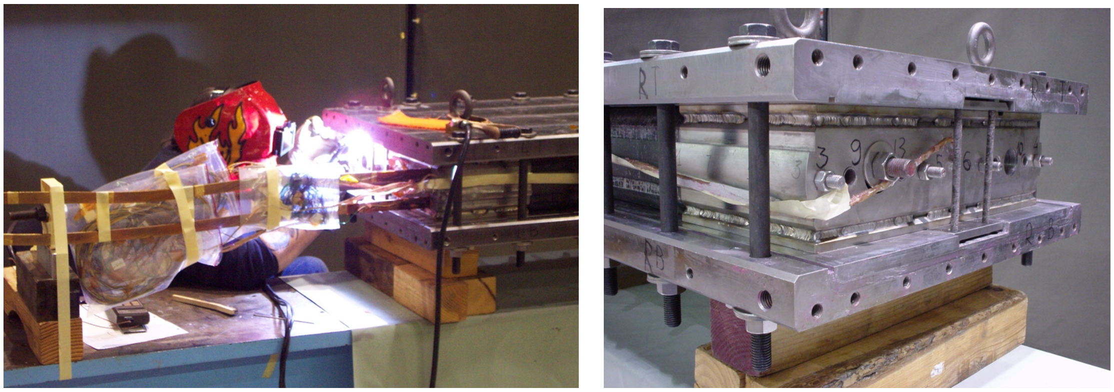


Figure 39. End-side plate welding on the outside perimeters.

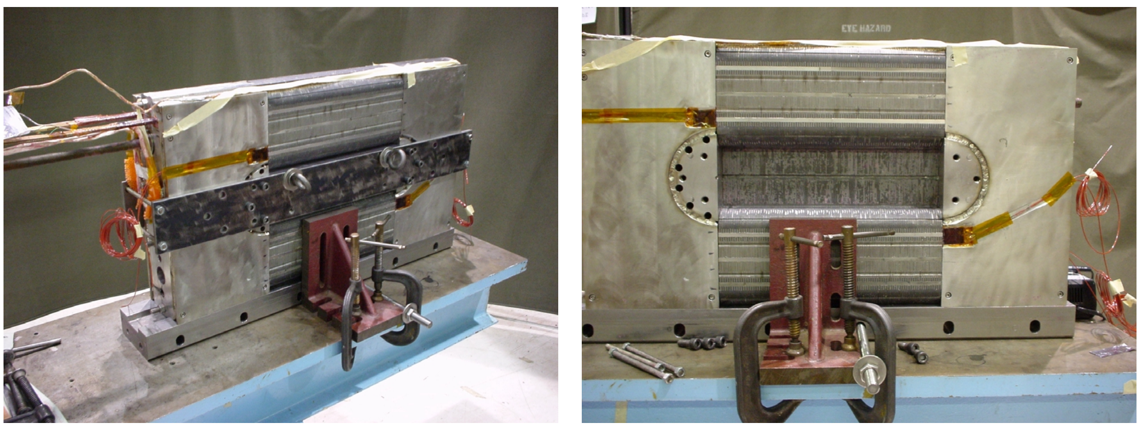
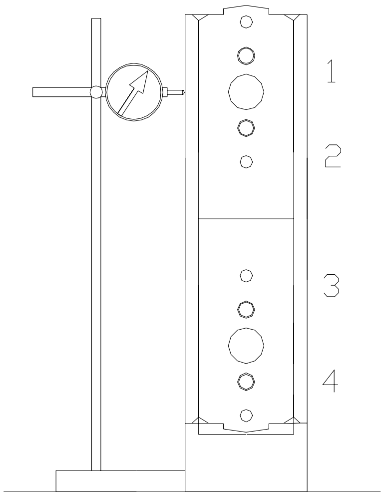


Figure 40. End-side welding on the inside radii.

End side-plates welding were performed inside of the impregnation fixture (without side bars). An outside perimeter of the each end was first welded using short skip passes on different sides. Then the magnet was vertically oriented and inside welds were performed using the same technique (Fig.39,40).

Size Control and Shimming

After ends welding the collared coils have been vertically oriented and measured in two ways: on a granite table and on a metal table. The first set of data gives information on block twist and flatness, the second set - on block size variation. Four lines along the magnet were measured.



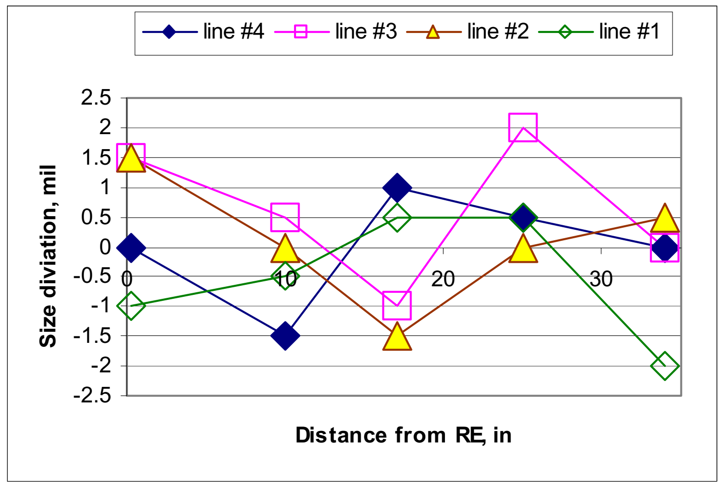


Figure 41. Twist measurement set up and data.

First data is shown in Fig x. after subtracting right from left side measurements, removing vertical and horizontal tilts, and finding position with a possible smallest deviation. As can be seen, block flatness is +/-1.5mil (if try to merge lines1 and 4).

Twist data is important for the magnet mechanics since three parts of the coil block have three different support structures and two different filler-spacers between the block and the skin. There are several possible twists in such design: straight section twist, straight section + coil end twist, and full block twist. The straight section has 1mil twist. The Led End has 2mil twist. The Return End has 2mil twist. The full block has ~1.5-2mil twist.

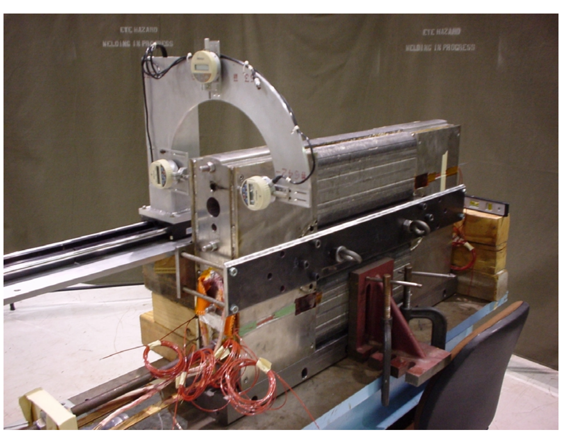


Figure 42. Outside dimension measurements.

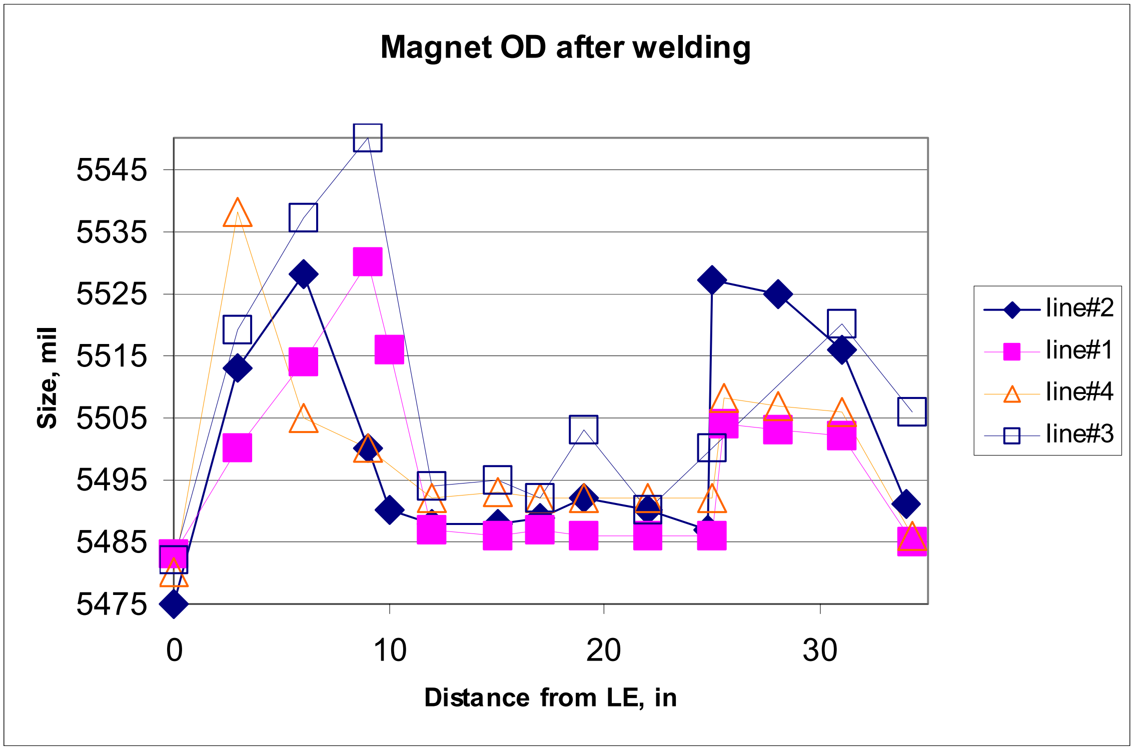
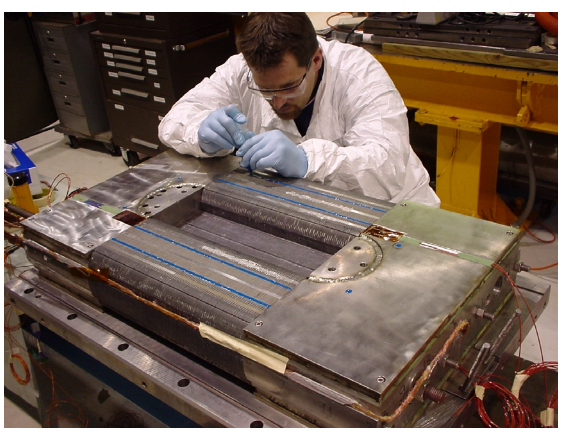


Figure 43. Profile of coil block OD.

Block's size variation presents in Fig x. The magnet has conical surfaces at the ends. Based on the measured information and taking into account the filler's geometry, it was decided to use a 20-mil shim at the straight section and a 40-mil shim at the ends. For correct shaping of the end shimming, all end's surfaces have been mapped relative to the end's stainless steel filler (a mock up). All shims were glued by Stycast to the coil block with a pressure using parts of the impregnation fixture as a compressive base. The shims were made of annealed copper for better contact between the coil block and the ruff-laminated surfaces of the iron yokes or end fillers.



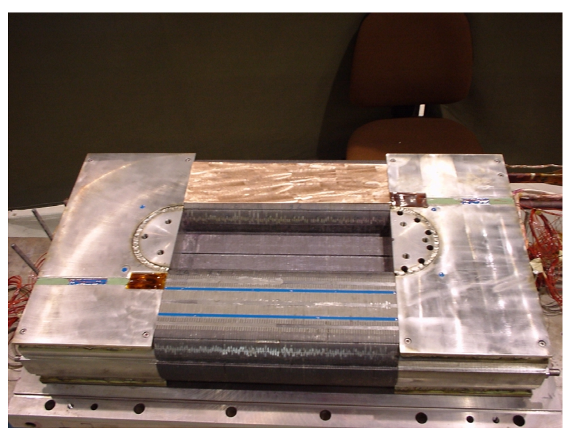
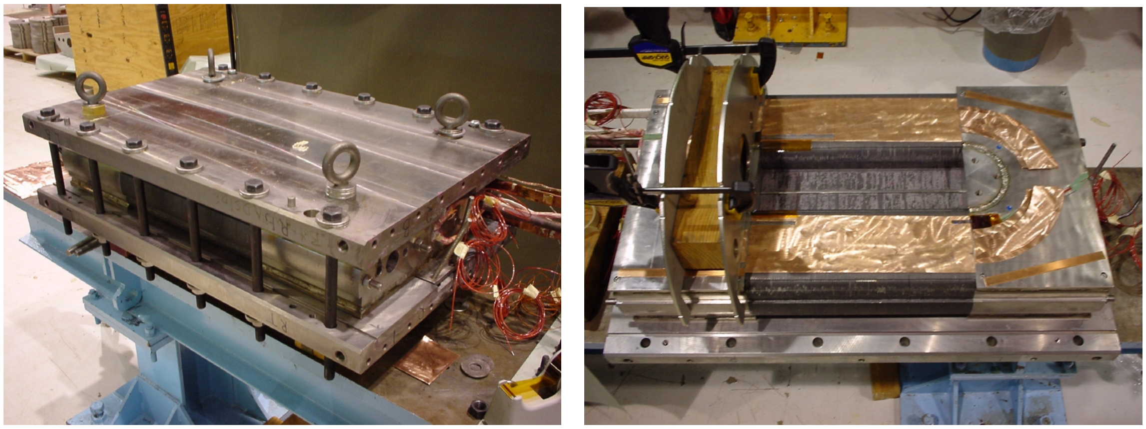


Figure 44. Shimming of the straight section

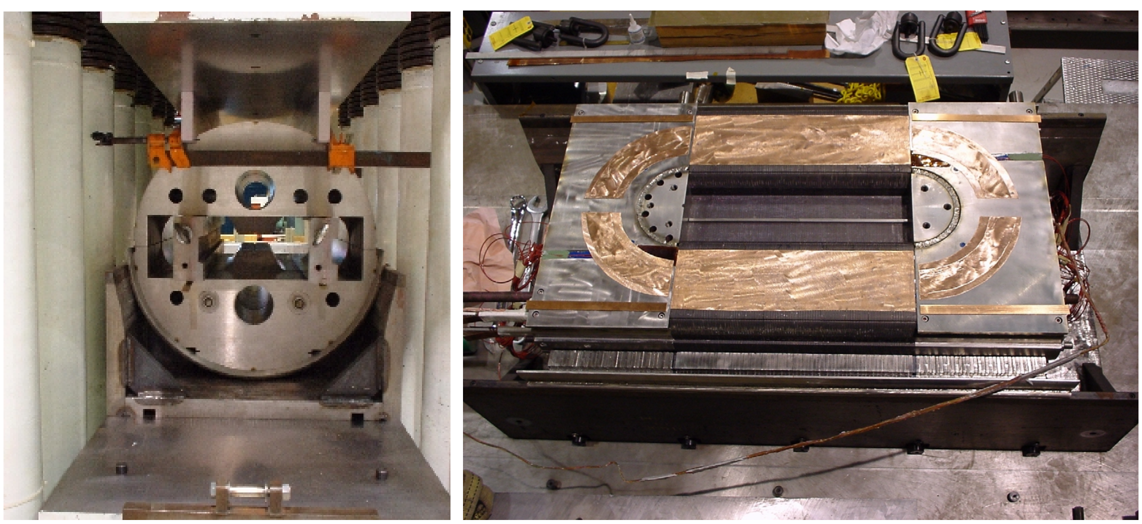


a) b)

Figure 45. Shim compression (a) and mapping of the ends using filler mock up (b).

Yoking

The shimmed coil block was placed into a skin-yoke structure. The bottom portion of this structure was preliminary straightened under pressure as shown in Fig 46. Two sidebars from the potting fixture substituted the coil block. Such exercises also help control the entire magnet shimming. The yoke gap was expected to be ~50mil at the magnet body and gradually got to "0" at the magnet ends.



a) b)

Figure 46. Checking of the shims under pressure (a) and final view of the magnet shims (b).

Following pictures show the magnet assembly layout and relative strain gauges location on the half skin.

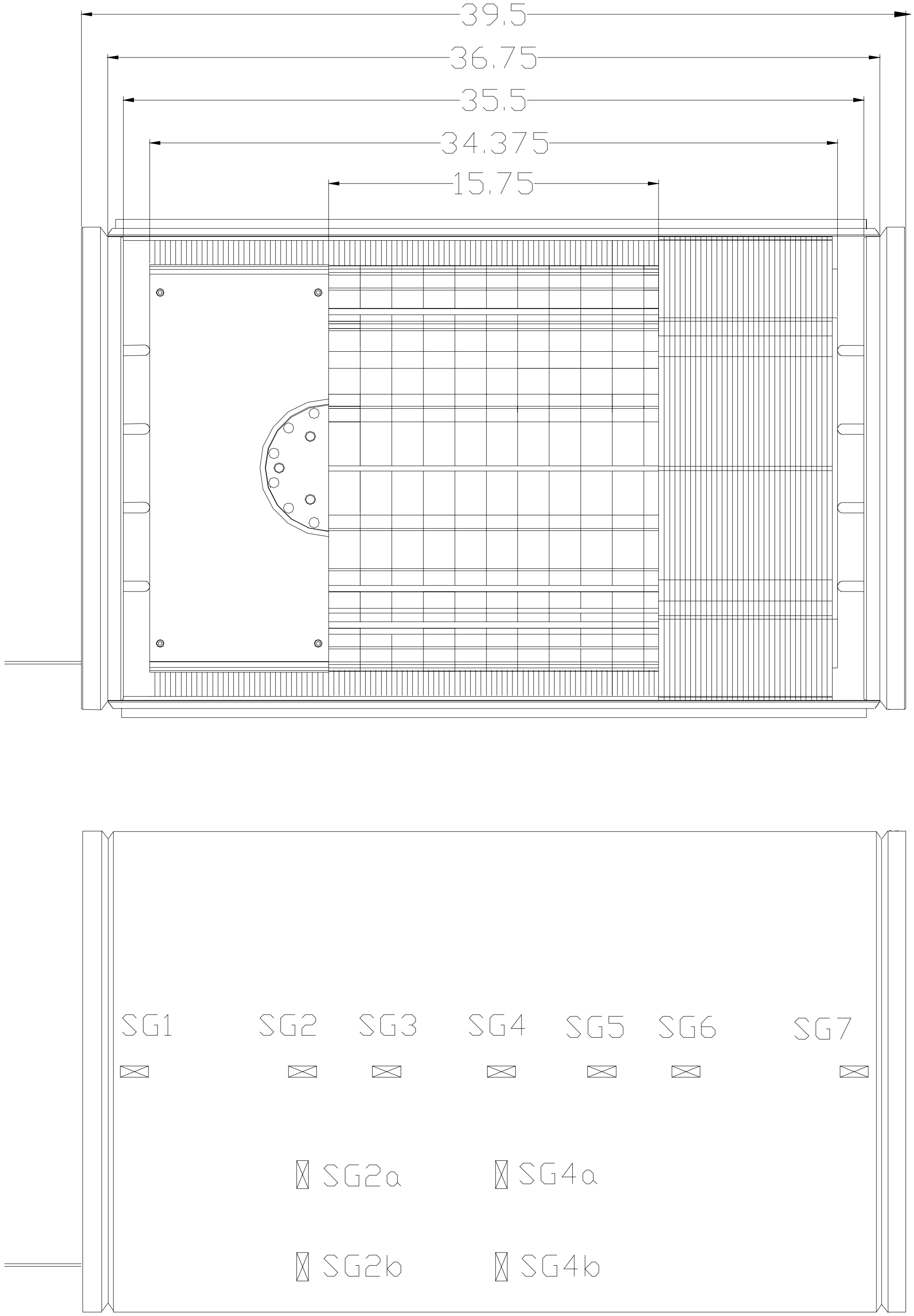


Figure 47. Schemes of the magnet assembly and skin gauges location.

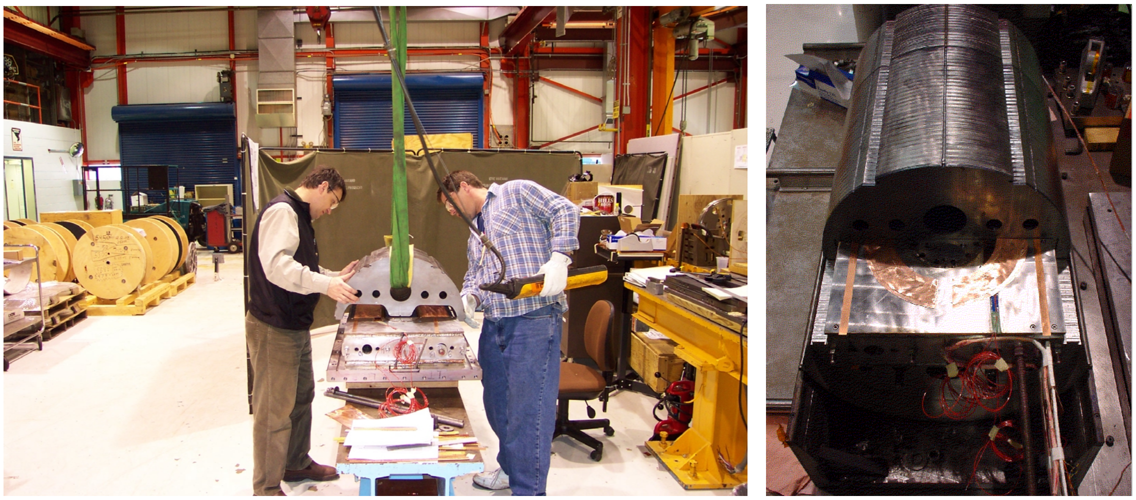
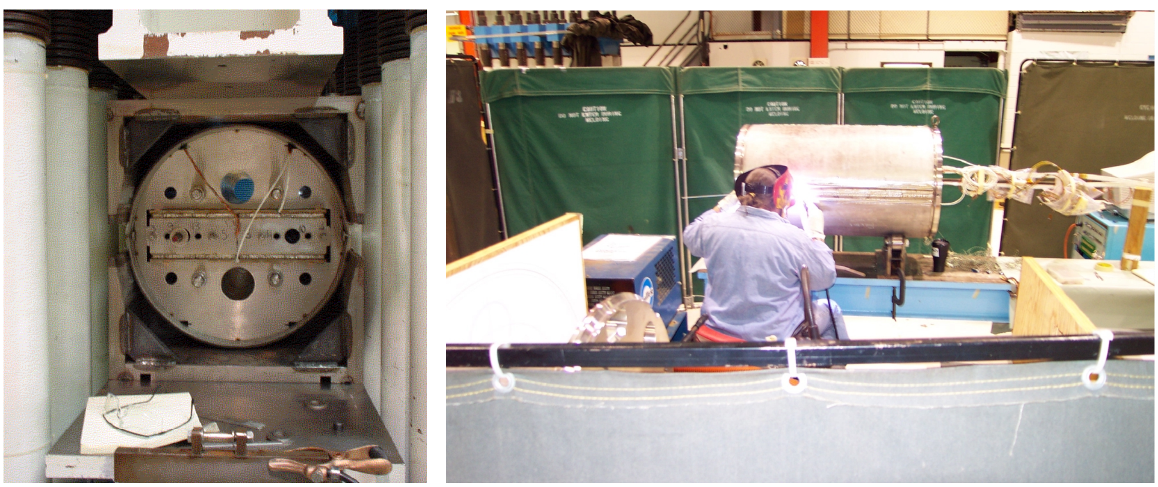


Figure 48. Magnet yoking.

Skin welding

Both half-skins have been partially (50%) hand welded together inside of the press using a tack-weld and skip-weld techniques. Final 4 passes were performed outside of the press and after the end plates installation.



a) b)

Figure 49. Skin welding inside (a) and outside (b) of the press.

Distances between pushers have been controlled in several places along the magnet while welding. The data is presented on Fig 50.
Both end plates were welded on to the skin. One skin was instrumented with 11 resistive strain gauges as shown on Fig 47. All over time-stress data is shown on Fig 51-52 for two magnet cross-sections and along the skin.

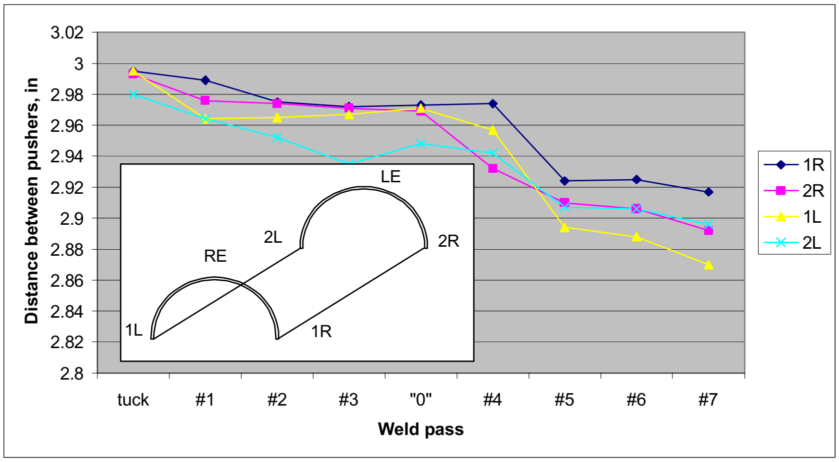


Figure 50. Change of a distance between pushers during welding.

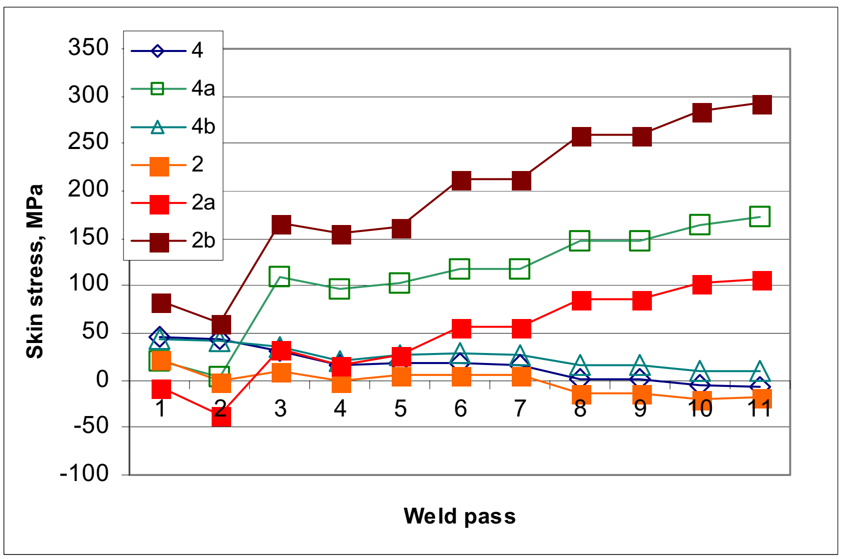


Figure 51. Stress history for the azimuthally oriented skin gauges.

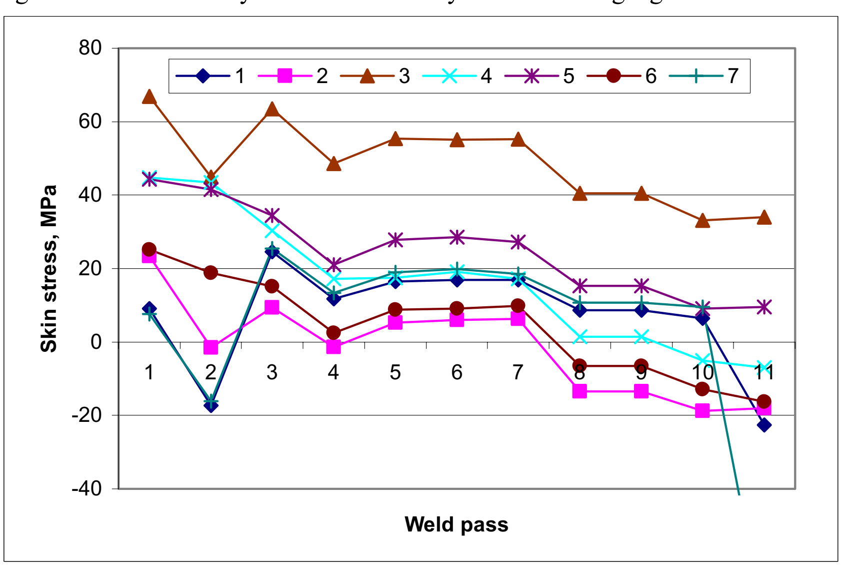


Figure 52. Stress history for the longitudinally oriented skin gauges.

Hypetronics Connectors

Appropriate wiring has been made before both end plates installation. All magnet instrumentations were connected to the 5 hypetronics connectors according to the note “VMTF Test Stand Magnet/DAQ System Interface. Magnet HFDC-01”. The connectors were electrically tested before magnet shipment.

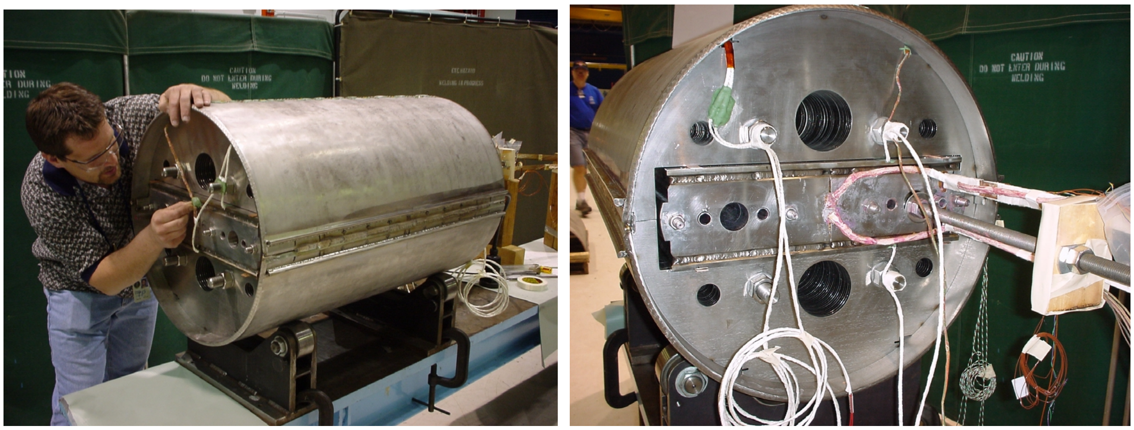


Figure 53. View of Lead and Return Ends wiring

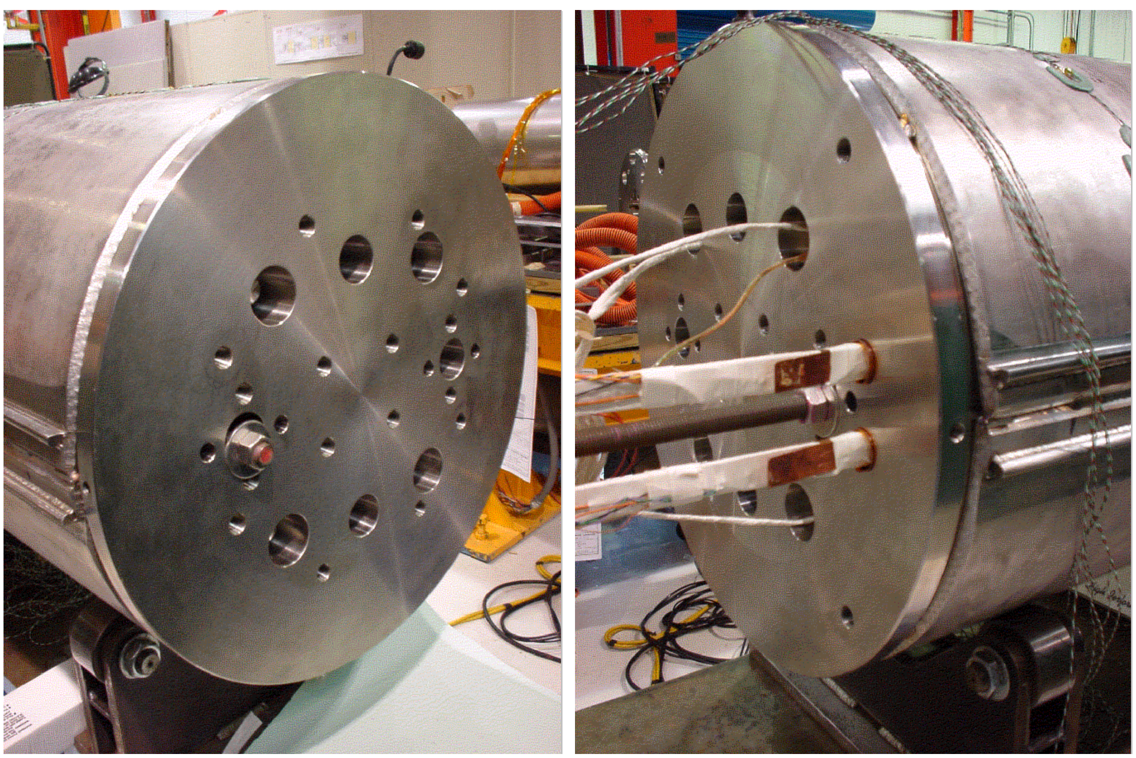


Figure 54. Magnet’s End Plates before welding.

Figure 55. Connector assembly.

Bullet loading

The end bullets were used in the magnet for the end load controlling at different stages. The first model's goal for a warm bullet's load was ~1100lbs or 500kg, to remain the bullet-end part contacts after magnet's cool down (what is ~5% of max estimated load). It should help measure electromagnetic forces transferred to the end plates.

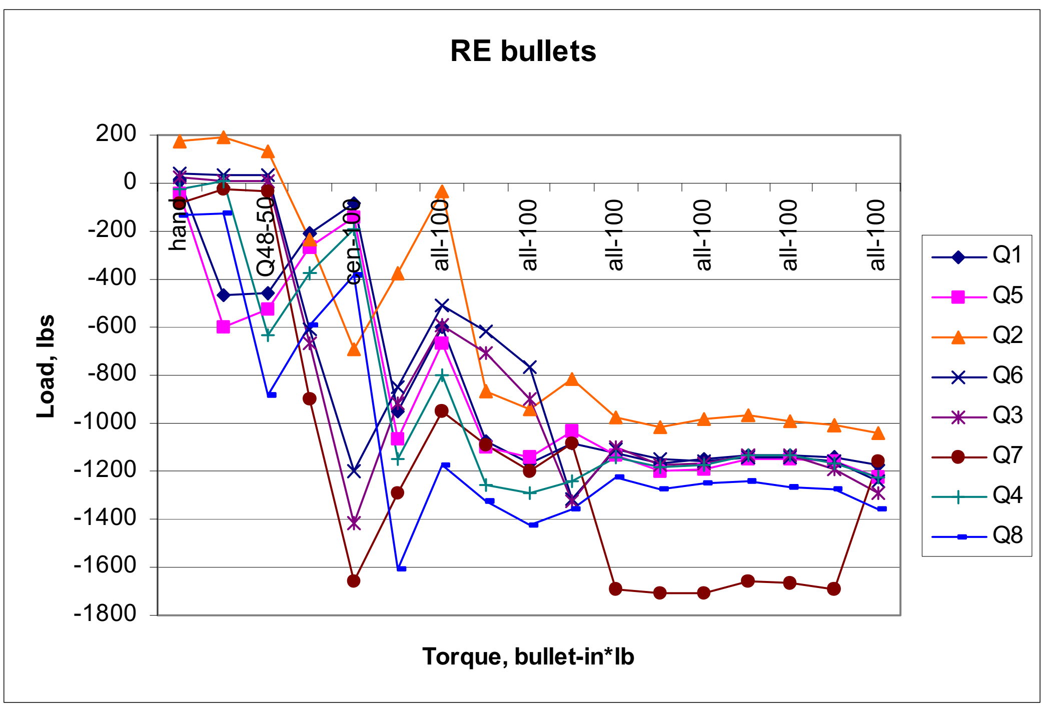


Figure 56. Loading of the Return End Bullets.

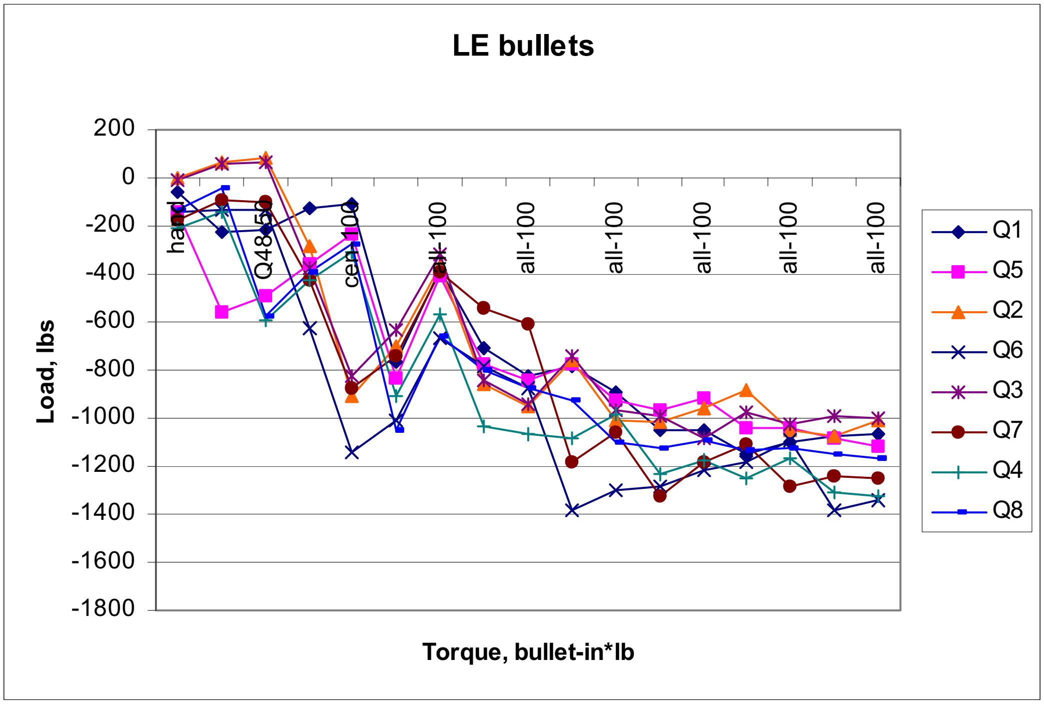


Figure 57. Loading of the Lead End Bullets.

Part of the magnet's suspension.

A special double plate (G10 and steel) was attached to the magnet's Lead End. It is a part of the magnet suspension into a cryostat. Set of special made fillers permanently support the magnet leads and provides cable straightness.

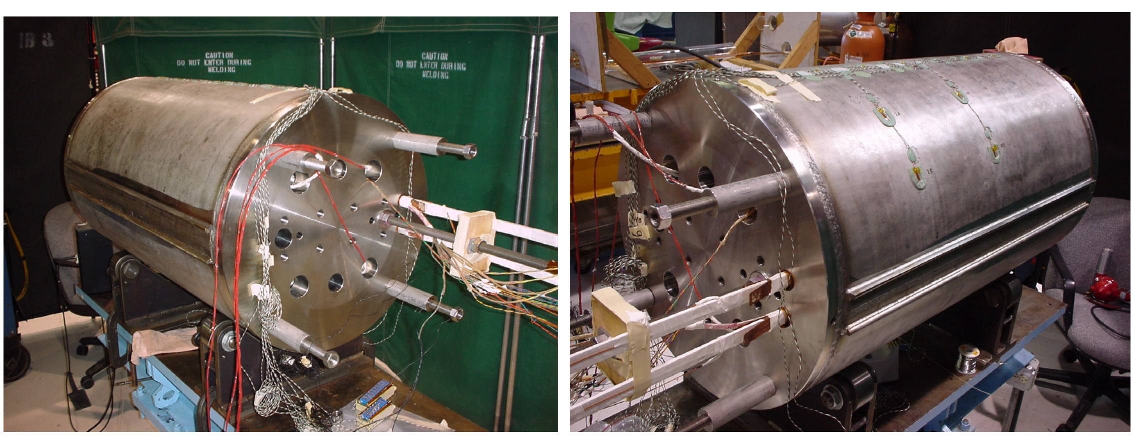


Figure 58. Magnet before the double plate installation.

Figure 59. Final magnet overview.

Figure 60. Magnet ready for transportation.

Final Electrical Test

Hi-Pot tests up to 1 kV were performed on the magnet to check current leakage between coil-to-ground and up to 600 V to test coil-to-heaters and heater-to-ground. The current was less than 0.04 μA at 1 kV for the coil and less than 0.18 μA at 600V for the heater.

Parameter	Top coil	Bottom coil	Total
Resistance, mΩ	252.3	251.6	503.8

Table 7. Magnet resistance.

Parameter	Total magnet final reading	
	1kHz	20Hz
Inductance, mH	1.04376	2.26008
Quality Factor	2.32	0.52

Table 8. Total magnet electrical measurements.

Parameter	Half coil final reading	
	Top coil	Bottom coil
Inductance, μH	754.36	747.66
Quality Factor	1.50	1.37

Table 9. Half coil electrical measurements @ 1kHz.

Parameter	Half coil final reading	
	Top coil	Bottom coil
Inductance, mH	3.96506	4.01063
Quality Factor	0.072	0.073

Table 10. Half coil electrical measurements @ 20Hz.

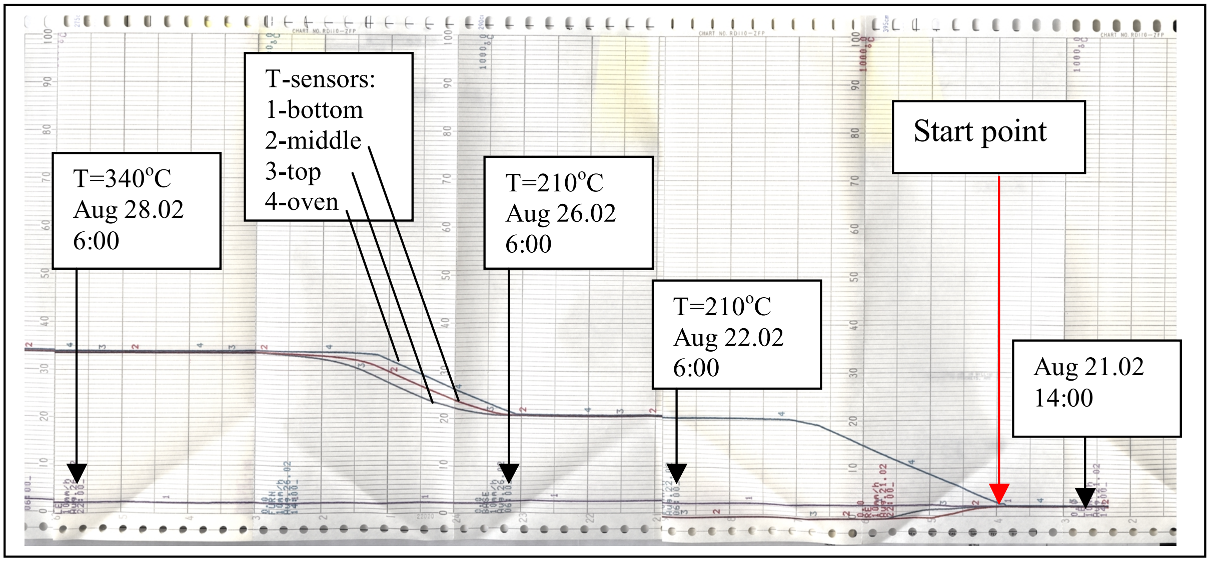
REFERENCES

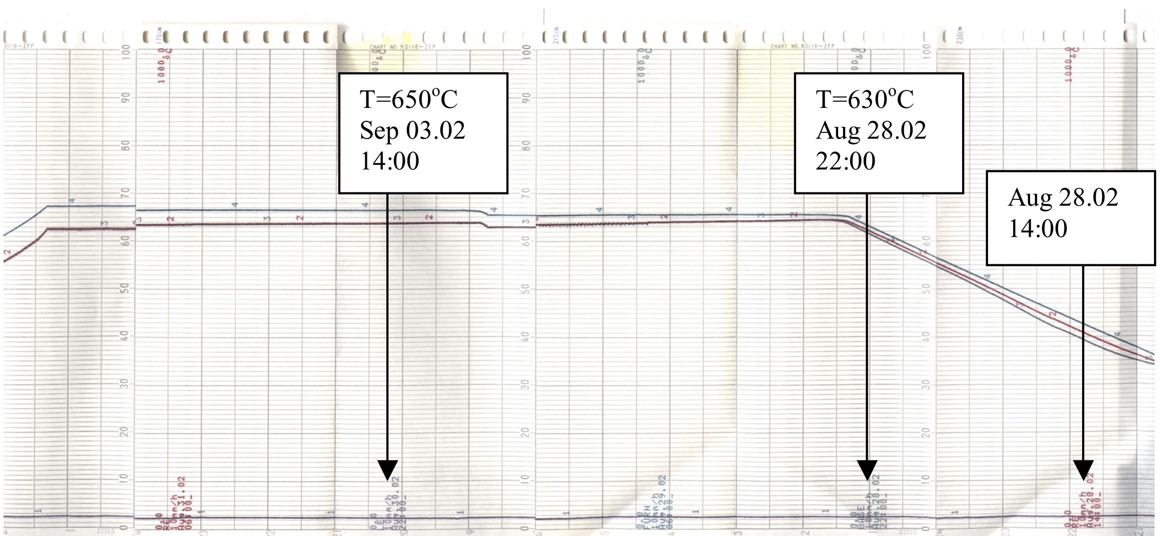
[1] "Design Study for a Staged Very Large Hadron Collider", Fermilab-TM-2149, June 4, 2001.

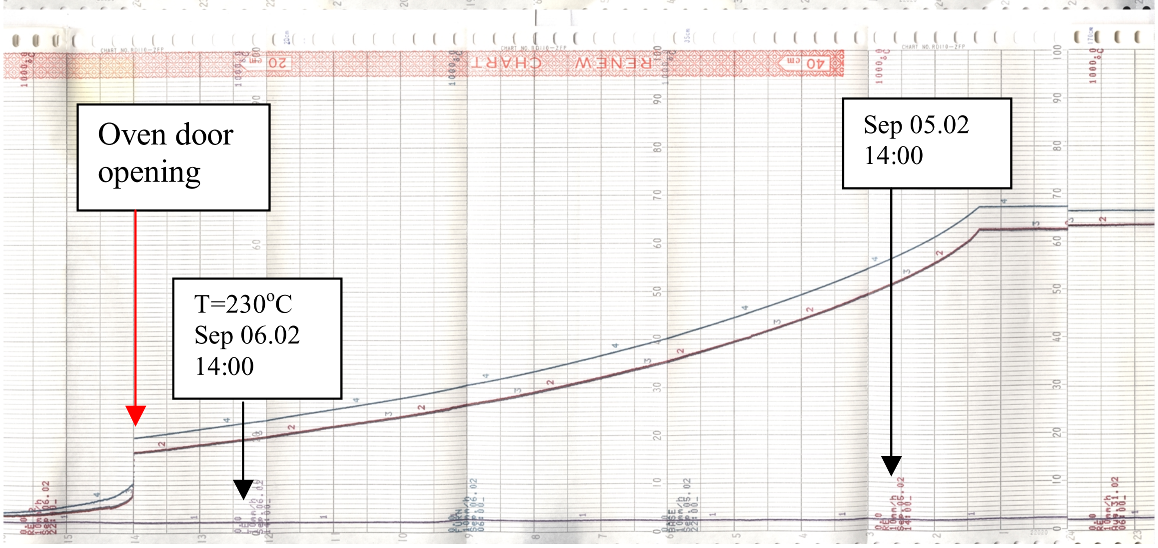
[2] I. Novitski et. al, "Development of a Single-Layer Nb3Sn Common Coil Dipole Model"
TD-02-002.

[3] G. Ambrosio et al., "Development and Test of a Nb_3Sn Racetrack Magnet Using React and Wind Technology", CEC/ICMC'01, Madison, WI, July 2001.

Appendix A. Cable reaction cycle


T=340°C Aug 28.02 6:00
T-sensors:
1-bottom
2-middle
3-top
4-oven
T=210°C Aug 26.02 6:00
T=210°C Aug 22.02 6:00
Start point
Aug 21.02 14:00


T=650°C Sep 03.02 14:00
T=630°C Aug 28.02 22:00
Aug 28.02 14:00


Oven door opening
T=230°C Sep 06.02 14:00
Sep 05.02 14:00